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STUDY OF LARGE LAUNCH VEHICLES UTILIZING SOLID PROPELLANTS

FINAL REPORT

SUMMARY

Submitted to

George C. Marshall Space Flight Center
Huntsville, Alabama

CONTRACT NAS 8-2438

10 February 1962

THE BOEING COMPANY
AERO-SPACE DIVISION
SEATTLE, WASHINGTON

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Back of title page

Page 38

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CONTENTS

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I. INTRODUCTION

This report is a summary of the important system parameters and operational considerations associated with the utilization of solid propellant motors in large launch vehicles having high-energy liquid-propellant upper stages, as determined by a study performed under contract NAS8-2438, the NASA Marshall Space Flight Center. The study was conducted in three phases.

Phase I, described in Volume I, D2-20500-1, was a study of a family of 22 vehicles of both two and three stages for payloads of 50,000, 100,000 and 350,000 pounds delivered to a 307-nautical-mile orbit. All vehicles consisted of a single LO_2-LH_2 upper stage combined with one or two solid stages. Maximum effort was made to collate and use data from the previous solid-liquid vehicle studies conducted by members of the solid rocket industry. Attention was given to the developmental and operational problems of the solid rocket concept variations such as single unitized motors, clustered unitized motors, and clustered segmented motors.

Phase II—described in Volumes II, IV, and V, D2-20500-2 (classified), -3, -4 (classified), and -5—consisted of the configuration and evaluation of a more select group of vehicles. Four basic vehicles corresponding to the Saturn C-1, C-3, C-4 and the Nova payload-carrying capability were selected. Also, a variation of the C-3 type vehicle was studied to determine the effects of segmented versus unitized solid motors in the first stage; a variation of the C-4 type was studied to evaluate the effect of lateral-staging.

The payload for the C-1 type vehicle was established as 30,000 pounds and the payloads for the C-3, C-4 and the Nova type vehicles were maintained as 100,000, 180,000 and 350,000 pounds respectively. The study also covered the technical approach to the design of these vehicles, an evaluation of the manufacturing and operational problems, and the ground support facilities concept. A description of the six vehicles with vehicle drawings and weight and performance characteristics is presented in this volume.

The particular configurations studied were identified as:

C-1 type—1-S1	(segmented)
C-3 type—3-SC4	(segmented)
C-3 type—3-UC4	(unitized)
C-4 type—4-UC4	(unitized)
C-4 type—4-UC6L	(unitized and laterally staged)
Nova type—N-UC4	(unitized)

The Phase III portion of the study, reported in Volume III, D2-20500-3, emphasized the cost and funding aspects of the vehicles configurated during the Phase II study. The cost per pound of payload in orbit for each configuration, with a breakdown of both direct and indirect system costs, was determined. A proposed fiscal year expenditure is presented in Volume III.

The scope of the study was partially limited by the establishment of ground rules which fall into two categories: 1) those established by contract prior to and following the Phase I study and 2) those established by Boeing on a "best engineering judgment basis" to allow the study to proceed on the broadest front possible while the impact of those ground rules were considered independently. The ground rules of the study are given in the appendix of this volume.

II. DESIGN PARAMETERS

SELECTION OF STAGING RATIO

In general, two-stage solid-liquid vehicle cost will approach optimum when the design is determined by minimum launch-weight stage ratio. When performance optimization cannot be achieved due to a desire to utilize existing upper stages or engines, the stage ratio should be chosen to minimize launch weight to the extent possible. For example, the C-4 type vehicle upper-stage engines were chosen to be the same as on the C-3 type vehicle in order to permit the use of a modified S-II stage in each case. This choice resulted in a vehicle which could not be optimized on a minimum weight basis since the second-stage thrust was limited to less than that desired. An analysis of the C-4 type vehicle (see Figure 1) made by rubberizing both liquid and solid stages, indicated that the first stage would be larger when optimized for minimum cost for payload delivery than when optimized for minimum total vehicle weight. It is most significant, however, that the cost varies only slightly over a wide range of ideal staging velocities. As such, the minimum point is very sensitive to such factors as vehicle inert weight, especially that of the second stage. Hence, the vehicle designer has a considerable degree of flexibility in determining stage ratios without undue concern about effects on program costs.

TWO-STAGE VERSUS THREE-STAGE

A three-stage vehicle, using solid propellant first and second stages, should be considered only when the existing liquid stage, when used as a second stage, cannot deliver a specified payload. As shown in Table 1, on the three-stage arrangement for the 22 vehicles of the Phase I study, vehicle weight (and therefore cost) is higher, reliability is lower, and development time is greater. Also, facility requirements are increased for the three-stage vehicles due to increased vehicle assembly and checkout time. Even though an increase in number of vehicles

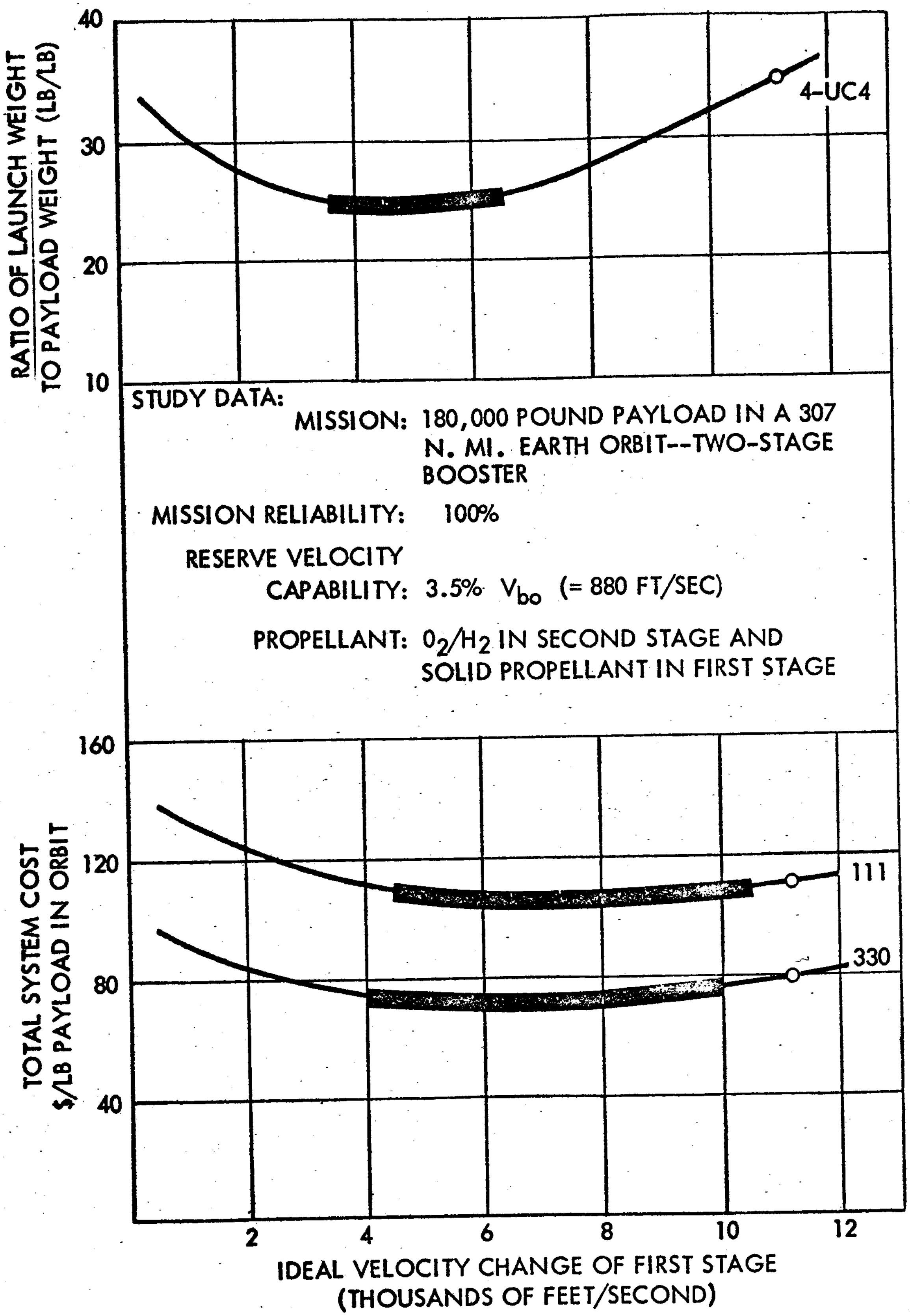

RATIO OF LAUNCH WEIGHT TO PAYLOAD WEIGHT (LB/LB)
40
30
20
10
4-UC4
STUDY DATA:
MISSION: 180,000 POUND PAYLOAD IN A 307 N. MI. EARTH ORBIT--TWO-STAGE BOOSTER
MISSION RELIABILITY: 100%
RESERVE VELOCITY CAPABILITY: 3.5% V_{bo} (= 880 FT/SEC)
PROPELLANT: O_2/H_2 IN SECOND STAGE AND SOLID PROPELLANT IN FIRST STAGE
TOTAL SYSTEM COST $/LB PAYLOAD IN ORBIT
160
120
80
40
111
330
2
4
6
8
10
12
IDEAL VELOCITY CHANGE OF FIRST STAGE (THOUSANDS OF FEET/SECOND)

Fig. 1

Table 1

VEHICLE COMPARISON CHART

Configuration	Launch Wt (Million Lbs)	Cost ($/Lb) 10 Units	Cost ($/Lb) 330 Units	Operational Availability (Months)	Stage Reliability (Percent Successful, First 10 Units)
2-Stage Vehicles					
50-2-I		141	1453	64	65.0
50-2-II	1.34	165	1675	76	58.0
50-2-III		164	1788	57	58.0
100-2-I		115	959	73	63.5
100-2-II	2.68	133	1162	85	54.0
100-2-III		134	1190	64	54.0
350-2-I		71	551	88	63.0
350-2-II		91	620	91	61.0
350-2-II_a	9.37	98	670	85	54.0
350-2-III		98	602	74	61.0
350-2-III_a		85	636	71	54.0
3-Stage Vehicles					
50-3-I		197	2280	79	55.5
50-3-II	1.53	216	2618	81	48.5
50-3-III		205	2490	64	48.5
100-3-I		150	1645	88	53.5
100-3-II	3.05	170	2080	91	40.0
100-3-III		165	1884	70	40.0
350-3-I		89	879	106	51.0
350-3-II		121	1220	110	38.5
350-3-II_a	10.68	125	1185	104	38.0
350-3-III		125	1120	83	38.5
350-3-III_a		99	1035	80	38.0

350-2-II_a

- 350 — 350,000-Pound Payload
- 2 — Two-Stage Vehicle
- II — Family
  - I Single Unitized Solid Motor
  - II Clustered Unitized Solid Motor
  - III Clustered Segmented Solid Motor
- a — 160 Inch Case Diameter (Other Clustered Motors Use 120-Inch Case Di

launched decreases cost differences by decreasing reliability differences, the two-stage vehicle remains more economical.

UNITIZED VERSUS SEGMENTED MOTOR DESIGN

Vehicles utilizing unitized motors will be more economical in terms of dollars per pound of payload delivered to orbit. Cost analysis of the unitized and segmented versions of the C-3 type vehicle indicated a 6 percent advantage for the unitized design. Motors having low length-to-diameter ratios, as those of the C-3 vehicle do, are least affected by the choice of unitized or segmented design. Consequently, it can be expected that the economic difference will increase in favor of the unitized design in those cases where greater motor length to diameter ratios exist.

ENGINE-OUT CONCEPT

Engine-out capability should be incorporated in LO_2-LH_2 multiengine stages presently being programmed for manned vehicles because of the low engine predicted reliability due to the present state of development of liquid-engine systems. Stage ratios of vehicles having engine-out capability should be optimized on the basis of all engines operating because engine-out capability is required only during early vehicle launchings. Initial payload rating would be that provided by the vehicle operating with one engine out. Payload growth capacity should be utilized at the point in the launch programs where engine-out operation becomes unnecessary due to reliability growth.

THRUST VECTOR CONTROL FORCES

The thrust-vector-control requirements are low for the large vehicles covered in this study because of the high vehicle moment of inertia characteristic of solid-liquid vehicles with a high concentration of mass at each end of the vehicle. Maximum total thrust deflection of less than 2 degrees and maximum side impulses of 1.68 percent of the stage impulse, decreasing to 1.0 percent for the Nova type vehicle, were required to meet thrust misalignment and wind conditions for the tandem-staged Phase II vehicles. This study, assuming that the solid motor nozzles are fixed, specified an allowance for thrust misalignment. Thus, the use of movable nozzles on the solid first stage would further reduce the thrust-vector-control force requirements.

DYNAMIC PRESSURE LIMIT AT STAGING

For booster size and stability of vehicles considered in the present study, burnout dynamic pressure should be kept below 200 psf for reasonable limitation of uncontrolled vehicle motions. Solid-liquid vehicles tend to give higher dynamic pressure than all liquid vehicles, due to shorter burn times, and they require longer staging times due to the long thrust decay period of solid motors. The long staging time requires low vehicle uncontrolled divergence rates, which can be obtained by reduction of dynamic pressure at burn out. Solid-stage clustering aggravates the staging problem by producing disturbing forces on the vehicle during solid-stage burnout. However, the clustering effects can be minimized by canting the solid stage nozzle axes through the vehicle center of gravity at burnout.

VEHICLE STABILITY

The important parameter for determining vehicle stability is time required for crew decision to escape with the autopilot failed; thus, a criterion of vehicle uncontrolled divergence rate is used rather than stability margin. The choice of vehicle instability margin was that time-to-double amplitude (the time required for an angle of attack to double in magnitude due to uncontrolled aerodynamic divergence) never be less than 2 seconds. Vehicle instability can be reduced by increasing vehicle fineness ratio, reducing dynamic pressure, and using fins. Fins were used on five of the six Phase II study vehicles where vehicle instability exceeded a time-to-double amplitude of two seconds at maximum dynamic pressure. Trajectory performance considerations, which cause the solid-booster maximum dynamic pressure to be higher than for a liquid first stage, result in greater booster aerodynamic instability effects. Aerodynamic instability is also increased by the clustering of first-stage motors on large boosters. Stability and control characteristics of the vehicles studied are shown in Table 2.

Table 2

STABILITY AND CONTROL CHARACTERISTICS

VEHICLE MAX q = 1200 PSF, M=2	1-S1	3-SC4 3-UC4	4-UC4	4-UC6L	N-UC4
NO FINS					
t_{2A}, Time To Double Amplitude, Sec.	1.6	1.6	1.7	1.7	3.4
FINS ON FIRST STAGE					
Fin Size, Ft^2 (Pitch only)	100 (1)	450 (1)	350 (1)	300 (1)	0
t_{2A}, Time To Double Amplitude, Sec.	2.0	2.0	2.0	2.0	3.4
δ (α=6°), Degrees	1.4	1.2	1.2	.9	1.0
FIRST-STAGE BURNOUT					
q, PSF	175	257	92	105	203
t_{2A}, Time To Double Amplitude, Sec.	4.3	3.2	8.8		5.8
SECOND-STAGE STARTBURN					
q, PSF	100	150	60	75	135
t_{2A}, Time To Double Amplitude, Sec.	3.4	2.4	3.7	12.6	8.5

(1) = Fins Sized For Maximum q Time To Double Amplitude = 2 Seconds

PROPELLANT MASS FRACTION

Solid stage mass fractions approaching 0.89 can be obtained at optimum chamber pressures. For solid motors having high length-to-diameter ratios, such as on the C-4 type vehicle, this is achieved at relatively high chamber pressures (700-800 psia) due to port-to-throat limitations penalizing propellant loading fraction at lower chamber pressures. Solid stages having low motor length-to-diameter ratios can achieve this mass fraction by operating at low chamber pressures; for example, a chamber pressure of about 450 psia was found to be best for the C-3 type vehicle. Since propellant specific impulse increases with chamber pressure, a solid stage employing high length-to-diameter ratio motors appears desirable for optimum performance. Segmentation lowers mass fraction by approximately 0.0075.

Liquid stage propellant mass fractions are shown in Figure 2. A reserve propellant allowance for a 3.5 percent variation in stage burnout velocity and a 1 percent propellant utilization allowance are included as inerts. The off-optimum staging of the 4-UC4 vehicle and the additional structure required for clustering in the 4-UC6L vehicle cause the degradations in mass fraction as shown.

BENDING FREQUENCY

Vehicle first-mode body-bending frequency should be greater than five times the design controlled pitch frequency to avoid structural coupling problems. The high solid-booster density influences the vehicle mass distribution so that the vehicle's first-mode bending frequency is reduced; this mass-distribution effect of the solid motors is not experienced with comparable all-liquid systems. The vehicle first-mode bending frequencies are not greatly affected by first-stage stiffness. An infinitely stiff solid first stage, approximately 40 percent of the total length of a million pound launch vehicle, increases the vehicle first-mode bending frequency approximately 20 percent. A low-vehicle fineness ratio, low pitch control frequency, and/or high vehicle stiffness should be incorporated to reduce structural coupling effects.

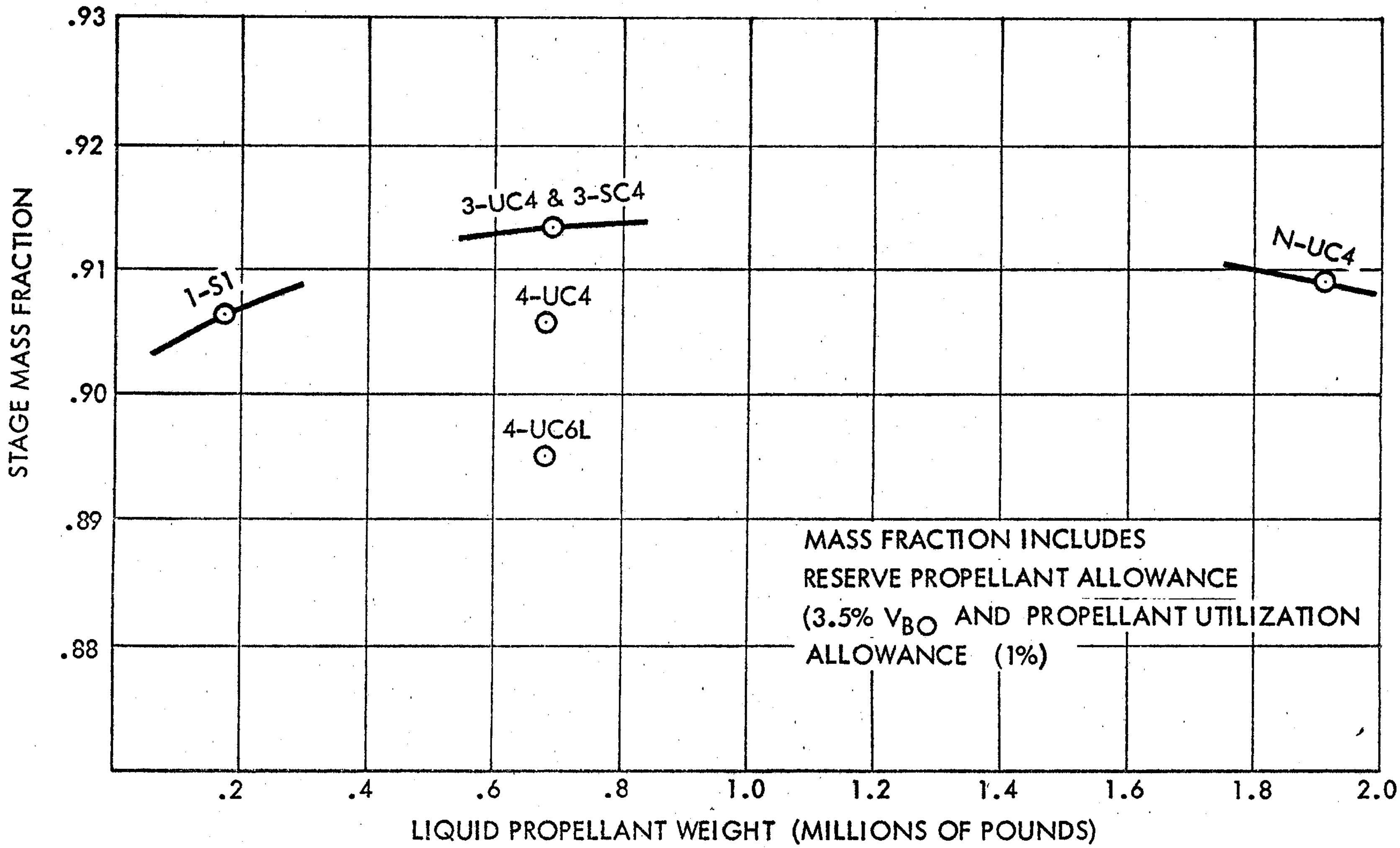


Fig. 2 PROPELLANT MASS FRACTIONS
LIQUID STAGE

SEGMENT JOINTS

As is characteristic of mechanical joint designs normally used in primary airborne structure, mechanical tolerances in the joints of segmented motor cases will not contribute to vehicle flexibility.

The joint is, in effect, a reinforcement of the case wall and is therefore more resistant to deformation than the wall proper. Combustion pressures of a practical operating level are sufficient to maintain tension loads in the joints under any external loading condition. For example, the most severe flight loading condition for the vehicles studied produced a net axial tension in the case wall of about 20 percent less than that imposed by the internal pressure. The vertical shear forces introduced in the cases were approximately 1/20 of the magnitude required to produce relative displacement of the joint interfaces.

LATERAL STAGING

The limited study devoted to lateral staging indicated no significant structural advantages over tandem staging. The increased inherent stiffness of the laterally staged vehicle was opposed by degradation in upper-stage mass fraction resulting from the integral stage clustering structure required of the concept chosen for analysis. Further investigations to determine the optimum clustering concept for vehicles employing lateral staging is suggested.

THRUST TERMINATION

A need for thrust termination of solid-motor boosters has not been indicated. Two situations in which thrust termination or thrust reduction could be of possible value are during escape and staging. An analysis using an Apollo-type escape system indicated that, for the vehicles studied, crew escape can be achieved without thrust reduction or termination. This conclusion must be reviewed for each specific case, however, since some payload escape system characteristics and booster performance characteristics could make thrust termination a requirement.

Serious consequences at staging from variations in motor burnout time can be avoided by canting the axes of the nozzles of the solid booster through the vehicle center of gravity at burnout. Of the vehicles studied, thrust termination will not be required if solid-motor thrust decay times are reasonably restricted, sufficient vehicle stability is provided, and/or retrorockets are used to cancel part of the thrust during the thrust decay period. In respect to the vehicles studied, thrust termination, which would impose serious weight and reliability penalties on the vehicle, is undesirable.

THRUST DECAY

The thrust decay of large solid motors is a significant factor in determining the staging sequence and vehicle stability requirements imposed by the staging time. Thrust decay characteristics of segmented and inert sliver unitized motors must be thoroughly defined in terms of: 1) thrust-time profile; 2) the point at which thrust vector control is no longer effective; 3) the distribution of thrust decays of clustered motors relative to each other; 4) the earliest point at which retrorockets may be fired to decelerate the booster; 5) retrorocket performance requirements of thrust and time.

MAXIMUM DYNAMIC PRESSURE

A small increase in launch weight results when maximum allowable dynamic pressure is reduced from 1200 psf to 1000 psf. For example, with the C-3 type vehicle the launch weight would increase 1.47 percent if the dynamic pressure limitations were reduced as stated. This weight increase, which is in the first stage where the dynamic pressure reduction is achieved by altering the solid-stage thrust program, results in a .26 percent increase in payload delivery cost. From this preliminary analysis, it would appear that the economic penalty for operating to a maximum of 1000 psf is not great and that the technical problems involved with the higher dynamic pressures should be the prime consideration.

THRUST-TO-WEIGHT RATIO

Thrust-to-weight ratio for the solid stage must be limited to between 1.5 and 1.6. The effects of maximum acceleration, maximum dynamic pressure, and staging dynamic pressure limits are summarized in Figure 3. Although the maximum dynamic pressure limit restricts the thrust-to-weight ratios to less than that desired, the economic penalty is as stated previously, small. The 8-g acceleration limit will not be of concern with burntimes up to 135 seconds.

PORT-TO-THROAT RATIO

Solid-motor port-to-throat area ratio should exceed 2.0 and preferably should be greater than 2.5 The use of lower values for port-to-throat ratio, which can result in excessive pressure drop along the grain and considerable erosive burning at the aft end of the grain, leads to a long thrust-time decay period for the solid motors. Another approach to reduction of the thrust-time decay period—the inclusion of inert sliver grains in the star-grained motors—should be evaluated for each specific application.

CONSERVATIVE GRAIN DESIGN

For maximum reliability and minimum performance deviations, conservative solid-motor grain designs, such as a circular port for segmented motors or a low-stress configuration for the unitized motor, should be employed. A neutral or slightly regressive thrust-time program should be used to minimize first-stage weight. However, the amount of regressivity is limited for the unitized grain design by the increased grain complexity.

HEAD-END PROPELLANT LOADING

Head-end loading of propellant is acceptable for segmented motors or the shorter unitized motors. Conservative grain design would preclude head-end loading in the longer unitized motors because of high grain stress during curing. Booting

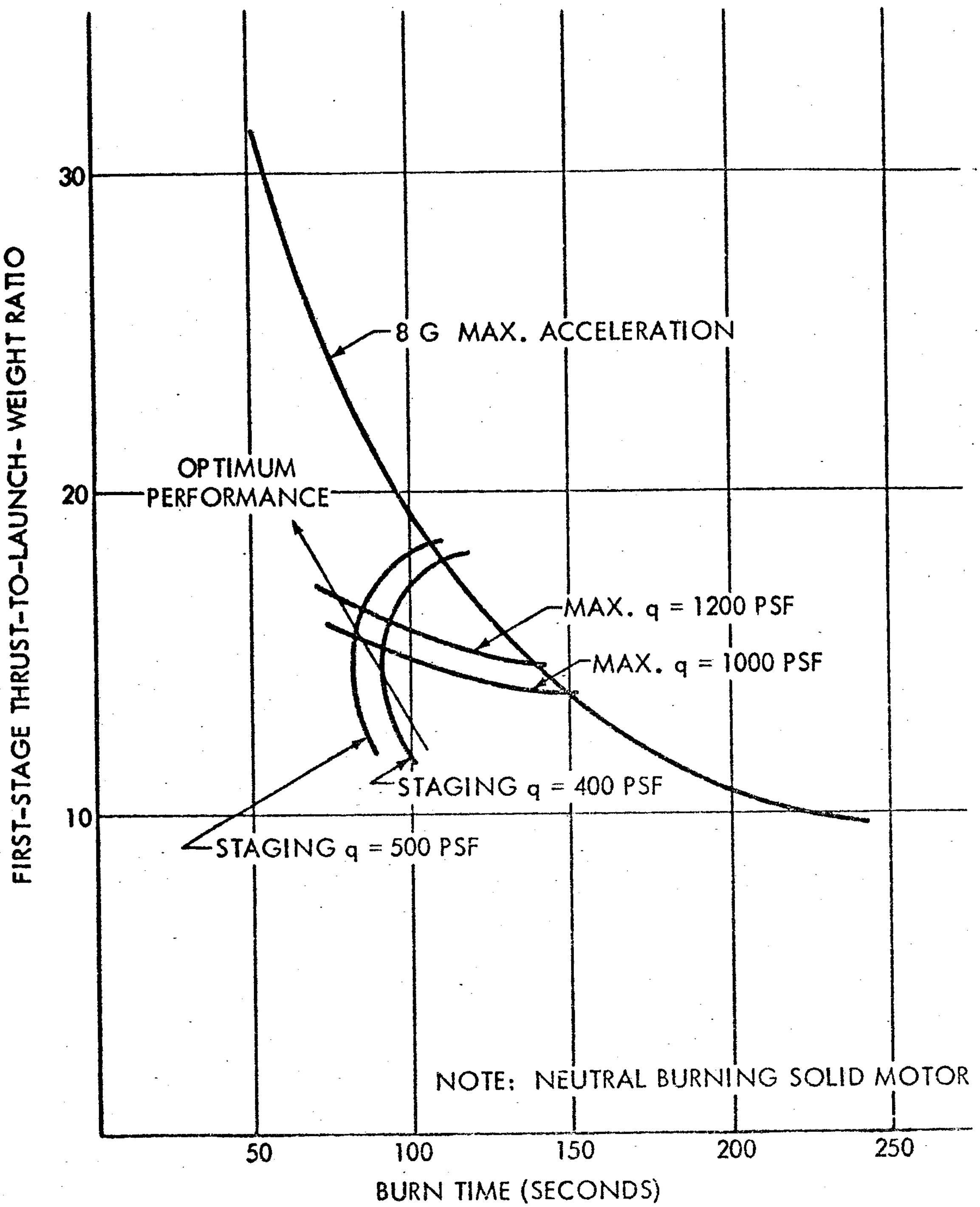


Fig. 3 SUMMARY OF DESIGN LIMITS

of the propellant grain will be required at the ends of all motors to allow for shrinkage during cure.

OPTIMUM CHAMBER PRESSURE

Chamber pressure that will produce optimum motor performance will vary with the ratio of inert motor weights dependent upon chamber pressure to inert weights independent of chamber pressure. When the above ratio goes up, optimum chamber pressure goes down. This effect will result in higher optimum pressures as the motor length-to-diameter ratio is increased. Another example of this effect is shown in comparing segmented and unitized motors. The additional segmented motor joint and insulation weight only slightly affect the optimum pressure by decreasing the above inert weight ratio. As a result the optimum chamber pressure for a segmented motor is higher than for an equivalent unitized motor.

AERODYNAMIC HEATING

For the vehicles studied, the heating environment of the forward interstage required the use of protective insulation. The requirement for insulation against aerodynamic heating is a function of the design trajectory, concept geometry, and the construction of the specific vehicle.

Any increase in vehicle cross-section in the direction of the air flow, and in particular the interstage areas of the vehicles, causes a rise in skin temperature. An analysis of the two-stage tandem vehicles configurated in the Phase I of the study indicated maximum temperatures in the order of 550° F in the liquid-stage-to-payload interstage area and 200° F in the first-to-second stage interstage area. The temperature variation between the two sections was due primarily to their skin thicknesses and distances from the nose of the vehicle. Based on the calculated temperature levels, protective insulation was considered necessary to prevent critical strength degradation of the forward interstage structure; the aft skirt, however, did not require insulation.

ACOUSTICAL VIBRATION

Acoustical noise levels were found to be compatible with state-of-the-art structures. During Phase I of the study, free-field sound pressure distribution were estimated, with the addition of a 5 decibel increment to represent the sound reflected from a 90-degree bucket-type blast deflector, for various vehicle stations. The maximum sound pressure level predicted for the study vehicles was 170 decibels in the nozzle exit region (Nova class vehicle). The structures of present-day silo-launched vehicles survive acoustic environments of the same order (i. e. Minuteman, 171 db).

SOLID PROPELLANT QUALITY ASSURANCE

A statistical analysis of solid-propellant variables that influence motor performance, grain physical integrity, and improper curing of propellant batches should be undertaken. Such an analysis would provide a basis for determining process quality control requirements and determine whether a limit may exist on the optimum grain size economical to cast. Large motors containing a large number of batches may permit a wider variation in individual batch properties than could be tolerated in smaller motors. However, where a large number of batches are cast into a single motor, the probability of including a defective batch is increased. Where continuous mixing of propellant is employed, it is customary to transfer propellant from the mixer to the casting site in casting vessels; thus subjecting the propellant to a degree of batch-type operation.

FIRST UNIT RELIABILITY

Booster characteristics causing major reliability variations are type of propulsion (solid or liquid), the number of propulsion units, and the number and the method of staging. Reliability analyses, of the 22 study configurations in the Phase I study and the 6 configurations of the Phase II study, determined first unit reliability and expected reliability growth. The first unit reliability for the final

6 vehicles are shown in Table 3. Historical data and manufacturer's design information were used as a basis for the study.

RELIABILITY VERSUS MOTOR SIZE

Historical data do not indicate a correlation between solid-motor size and reliability. The technical risk involved as motor diameter increases beyond that of those produced to date is believed worthy of consideration, however.

RELIABILITY VERSUS BURN TIME

Historical test data do not indicate a correlation between solid-motor burning time and reliability. Although the technical feasibility is now being demonstrated for motor burn times greater than 60 seconds, historical data is not available to substantiate the reliability of motors with longer burn times. Therefore, some technical risk is involved in the design of motors having longer burn times.

SUBSYSTEM REDUNDANCY

Redundancy should be used in the design of thrust vector control, ignition and flight control of solid and liquid stages, and the propellant feed subsystems of liquid stages. The significance of incorporating redundancy into these subsystems is evident from the vehicle reliability predictions shown in Table 3. A launch-pad-retained ignition system should be used for clustered solid boosters for maximum vehicle reliability without additional vehicle weight or complexity. On this basis, solid stage ignition reliability was assumed to be 100 percent.

Table 3

FIRST UNIT RELIABILITY PREDICTIONS

BASED ON HISTORICAL DATA

	1-S1	4-UC4 3-UC4 3-SC4		N-UC4	
FIRST STAGE					
Propulsion (Ignition, Etc.)	0.990	0.961		0.961	
TVC & Controls	0.970	0.913		0.913	
Structure	0.995	0.995		0.995	
Human Factor	0.999	0.999		0.999	
Stage Total	0.921	0.854		0.854	
SECOND STAGE					
Propulsion, Prop. Feed, Etc.	0.930	0.748	0.951*	0.804	0.915***
TVC, Controls & Inst.	0.950	0.814	0.968**	0.857	0.905****
Structure	0.993	0.993	0.993	0.993	0.993
Human Factor	0.985	0.985	0.985	0.985	0.985
Stage Total	0.767	0.510	0.771	0.577	0.693
Total Vehicle System	0.706	0.436	0.658	0.493	0.592

* Engine-Out Capability (10% Catastrophic Failures)

** One Thrust-Vector-Control Redundant

*** Redundant Valves, Etc.

****Redundant Servoactuators, Etc.

III DEVELOPMENT AREAS AND RECOMMENDATIONS

The previous section of this document has described the more significant design parameters and guides disclosed in the study of large launch vehicles. The following section of the document presents a summary of development areas that should be included in planning for further study or in the initial phases of vehicle design.

THRUST VECTOR CONTROL SYSTEM

Further study, supported by test programs, should be conducted to determine the optimum thrust-vector-control system. Thrust-vector-control methods should be studied in detail for one configuration with varying stability and several control laws to determine the most desirable vehicle control parameters for each system and allow an overall comparison of the systems. A brief survey of control methods for long burntime solid motors indicates that the main systems under consideration are nozzle fluid injection, auxiliary solid-rocket motors, gimbaled nozzles, and jet tabs. In Phase II of this study, fluid injection was selected because it is representative of methods currently considered feasible and is under intensive development for long burntime solid motors.

CLUSTERING STRUCTURES

Test evaluations and correlated analyses of structural concepts for clustering large solid motors should be conducted to determine the optimum approach to the problem and enable the selection of clustering structures that combine maximum reliability with minimum cost and offer an arrangement suitable to subsystem emplacement and access.

The clustering of large solid motors involves: 1) the integration of the highly stressed cases into an efficient load carrying structure; and 2) the accurate prediction of the dynamic characteristics of the structure. The feasibility of clustering large solid motors has been established through parametric studies—

the practical aspect of the problem remains to be solved. For example, the dimensional changes that occur independently between clustered solid motors at ignition and burnout present unique structural problems.

MOTOR CASE MATERIAL

Insufficient knowledge concerning the fracture mechanics and processing characteristics of materials suitable for large solid motor cases in the heavier gauges required for this purpose prevents the accurate determination of design safety factors and motor reliability.

Research and development of candidate materials should be intensified to establish basic fracture toughness data and the manner in which processing variables effect the occurrence of flaws. The study results would direct the choice of method for fabrication, processing and inspection that: 1) afford minimum case weight consistent with maximum reliability; 2) provide for the selection of a chamber proof-test pressure that would ensure the required service life.

Emphasis should be placed on the further evaluation of low-alloy, high-strength steels. Continued attention, however, should be given to annealed titanium as an alternate material and to the precipitation hardening nickel steels for future applications.

VEHICLE CONFIGURATION OPTIMIZATION

A detailed vehicle control dynamics study of two vehicles with varying numbers of first-stage solid motors should be made to establish configuration requirements for vehicle stability, stiffness, length-to-diameter ratio, boost control laws, and autopilot design. This study should examine the relative significance of independently variable parameters on vehicle configuration, using mathematical models of vehicle dynamic relationships,to provide design criteria for optimizing vehicle configuration.

MALFUNCTION SENSING

Solid-motor malfunction sensing devices should be given maximum development effort. The effectiveness of various sensing instrumentation must be continuously investigated and improved to ensure effective payload escape. The criterion for such devices should be immediate, accurate interpretation of sensed deviations and malfunctions.

SOLID-MOTOR THRUST DECAY

It is necessary to define the solid-motor thrust tail-off in terms of the time from loss of vehicle control to termination of solid-stage thrust by motor burnout or by forced termination such as by firing of retro-rockets to cancel solid-stage thrust at very low thrust levels. As discussed in the previous section, long thrust-decay times result in long staging times for solid-liquid vehicles. Thus, practical limits for minimizing the thrust tail-off of solid motors should be determined and their restriction on solid-motor design criteria such as allowable port-to-throat ratio and requirements for inert propellant slivers. For clustered motors, the probable distribution of thrust decay between motors should be analyzed, using historical data, to obtain statistical variations in motor burn time.

SOLID-MOTOR PERFORMANCE VARIATION

The influence of solid-motor performance variations on solid-stage performance should be analyzed. Variations in solid-motor performance parameters such as thrust, burning time, and total impulse can be predicted from historical data and knowledge of the vehicle environment. The solid stage should be designed to equal the minimum performance predicted for the stage.

SOLID-PROPELLANT GRAIN DESIGN CRITERIA

Definitive methods for predicting grain defect formation such as cracking, separation, and slump and the establishment of valid grain-design criteria based on propellant physical properties should be developed. This problem is currently under intensive investigation by a number of organizations. A close monitoring and collation of such information should be undertaken.

SOLID-PROPELLANT CRITICAL MASS

Experimental tests should be undertaken to further define solid-propellant critical mass and temperature, particularly during the partially cured state and, if necessary, determine the cooling methods required for control. Cured cylindrical composite-propellant grains 100 to 200 inches in diameter can be handled and stored safely at temperatures below 200°F according to studies by Thiokol Chemical Corporation and the Naval Ordnance Test Station. These studies were based on measurements taken on small propellant samples (up to 5 inches in diameter) and scaled to larger sizes of motors.

SOLID-ROCKET ATTENUATION OF RF SIGNALS

Further study of solid propellant combustion processes and the flow fields developed by clustered motor exhaust plumes must be made to define the seriousness of vehicle communication attenuation. Based on this data the design and location of antennas on the vehicle and the location of down-range tracking stations can be established. Solid-motor exhaust attenuates radio communication signals more than liquid exhaust because of the high electron density plasma generated by solid-propellant combustion.

DYNAMIC PRESSURE LIMITS

Further analyses should be made of dynamic-pressure-limit effect on vehicle performance and cost. While it has been shown that solid-liquid vehicles can give maximum dynamic pressures within the 1000 to 1200 psf region, the penalties or gains for exceeding these limits have not been definitively established. Further reductions in dynamic pressure may be possible, without sacrificing payload weight, by changes in thrust-time program and/or trajectory flight-path angle. Increases in dynamic pressure limits would require trades on crew escape systems, stability and control, cost, performance, and weight.

IV. FACILITIES AND TRANSPORTATION

HARDWARE MANUFACTURING

Hardware items can be manufactured with existing facilities. While some deficiencies exist, such as heat-treat facilities, present plants may be supplemented at less cost than constructing new plants. It is likely that these supplemented facilities would be supplied by industry if orders or recovery guarantees were provided.

Unitized motor cases can be initially fabricated with existing manufacturing facilities by welding together machined end rings of heat treated segments. However, study of the C-3 type vehicle indicated that improved case fabrication techniques, requiring new facilities, will eliminate the machined rings at critical welds. Stage inert weights would be reduced 7,600 pounds and inert costs decreased. Assuming no reliability change, the dollars per pound of payload delivered to orbit will be reduced by 2.5 percent.

PROPELLANT MANUFACTURING

This study revealed that the capacity of existing propellant facilities is not adequate to meet the requirements of the higher launch rates. Existing facilities for segmented motors are, with some supplementing, adequate for a development and production program at a low launch rate. Existing facilities are not adequate or easily revised to accomplish the development of large unitized motors. Figure 4 shows the relationship between the solid-propellant mixing capacity available within the country in 1961 and the requirements of this study program. The graph shows only the installed propellant mixer capacity and does not include casting, curing, and other necessary operations.

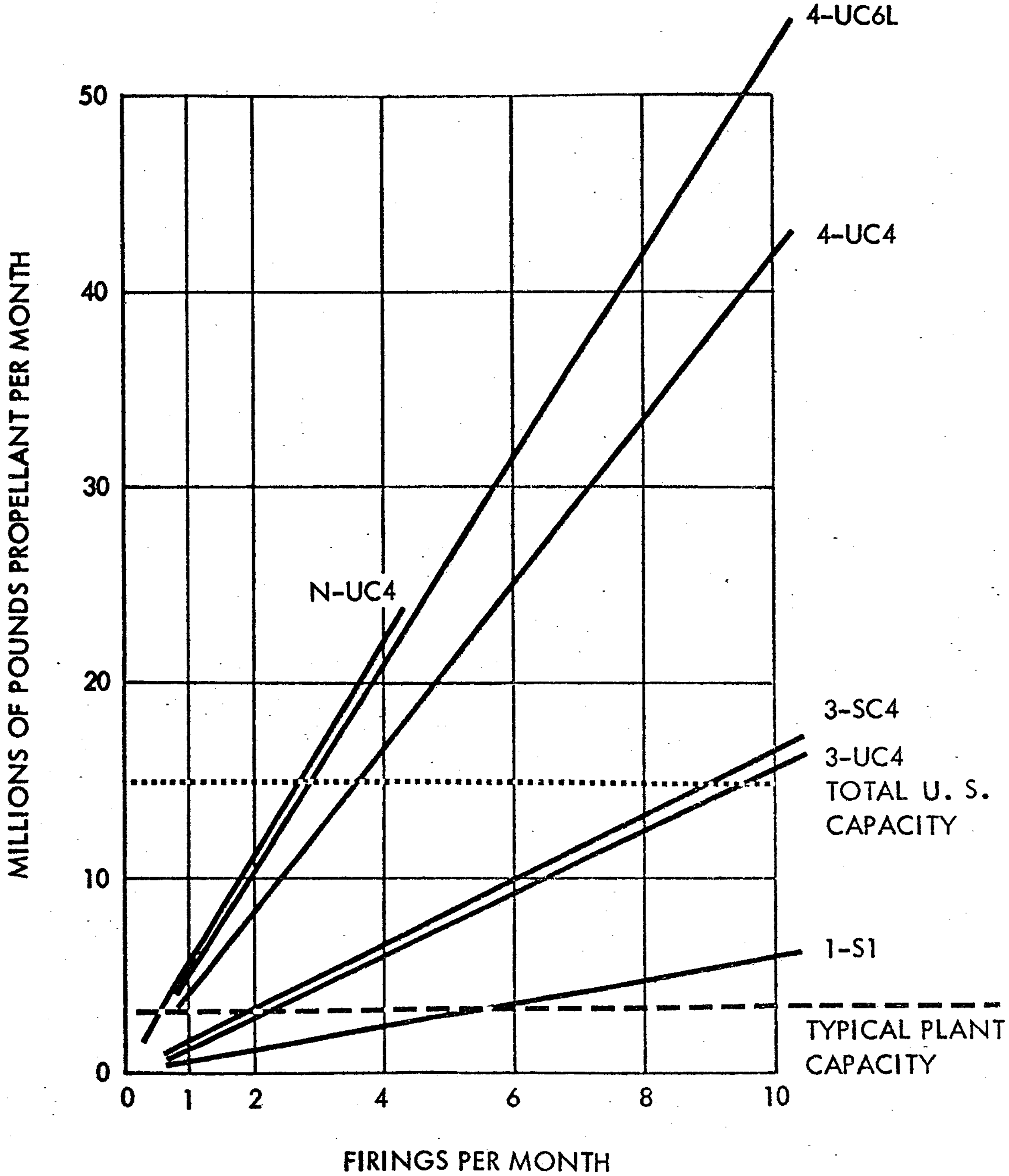


Fig. 4 SOLID-PROPELLANT PROCESSING CAPACITY VS. REQUIREMENTS

TRANSPORTATION

All methods of transporting large solid motors are limited by economic feasibility. Transportation by barge has no size or weight limitations except that loading facilities have to be furnished. Present rail transportation is limited to segments up to 156 inches in diameter and a weight of approximately 100 tons. Highway transportation should be considered only for short distances.

FACILITY LOCATION

The location of the development and production facility does not significantly affect overall program costs; however, unitized motors can most economically be produced on a navigable waterway within 50 miles of the launch complex. This production should include preparing motor cases and preparing, mixing, and casting solid propellants. With such an arrangement, long-distance transportation of large heavy loads would be minimized.

The location of motor production facilities close to the vehicle assembly and launch operations will 1) permit close integration of operation, facilities, and base transportation; 2) result in reduced load time for all launch rates; and 3) permit maximum utilization of handling equipment.

Total system costs, for 666 launches of the unitized C-3 type 100,000-pound-payload vehicle with a single unitized first-stage motor, were approximately 2 percent less for near-site unitized motor casting than for West Coast casting. Although the cost advantage would be less if facility activation costs were charged to the near-site concept, the problem associated with accumulating the necessary personnel and skills in a new area may be more significant.

AMMONIUM PERCHLORATE SUPPLY

A deficiency exists in the supply of ammonium perchlorate needed to meet the propellant production required by the higher launch rates of this study.

Additional facilities could be provided by industry on time if adequate incentives and guaranteed recovery are established early in the program.

ADDITIONAL FACILITIES

New methods of constructing heat treating furnaces should be investigated to provide capability for the large cases being considered. Localized heat-treat techniques should be developed from the laboratory stage. Spin-forming techniques should evolve to the larger sizes. Improved continuous mixing lines and quality control equipment should be investigated to provide an economically uniform product. Since both ammonium perchlorate plants and propellant mix plants will have to be constructed for the higher production programs, the possibility of integrating these facilities, and resulting economics, should be investigated.

MOTOR HANDLING

The equipment necessary to lift and handle the heavy motor weights at assembly can be simplified and held to a minimum by designing for specific functions and by combining various operations in the assembly sequence. The separation of operations permits all equipment to be used continuously with no redundancy. Launch rates can be increased by addition of equipment units. This method is suggested as a means to prevent obsolescence of facilities and equipment as configurations and launch rates change.

MOTOR CASTING AND CURING

Casting and curing of large unitized motors should not be done on the launch pad since this requires long launch-pad-occupancy times, resulting in increased land and launch facility requirements.

V. CONFIGURATION SUMMARY

Vehicles studied in detail are two-stage systems incorporating solid-propellant motors in the first stage and a liquid-oxygen liquid-hydrogen powered second stage. The liquid tankage is compatible with booster size and vehicle fineness ratio, and is of waffle-pattern monocoque structure with a honeycomb-construction common bulkhead separating the fuel and oxidizer. Two versions of internal-burning, case-bonded solid-propellant motors are considered in this study: a segmented, circular-port grain with uninhibited circumferential slots; and a unitized, five-point-star grain. Fixed fins are used to improve vehicle stability where required, and secondary fluid injection is used for thrust vector control. Characteristics of the vehicles studied are summarized in Table 4.

30,000-POUND-PAYLOAD VEHICLE 1-S1 (FIGURE 5)

This configuration, representing a C-1 type vehicle, uses a single 160-inch-diameter solid-propellant motor in the first stage and a single J-2 engine in the second stage. The use of single motors in each stage provides a high vehicle reliability, reflected in terms of a low cost per pound in orbit for the payload size. Segmented design is incorporated in the first-stage motor to minimize vehicle development time. A secondary fluid injectant is Freon pressurized by stored helium gas.

100,000-POUND-PAYLOAD VEHICLES 3-SC4 AND 3-UC4 (FIGURES 6 AND 7)

Two variations of a C-3 type vehicle were studied: the 3-SC-4 and 3-UC4. The 3-SC4 consists of a cluster of four 160-inch diameter segmented solid-propellant motors and four J-2 engines clustered to power the second stage representing a modified S-II Stage. The 3-UC4 has four 160-inch diameter unitized solid-propellant motors in the first stage; the second stage and payload are the same as the 3-SC4. The clustering concept utilizes cylindrical extensions of the motor case tied together by a tress network and heavy-framed semi-monocoque skin panels (see Figure 8). Secondary fluid injection uses a single Freon tank,

Table 4

VEHICLE CHARACTERISTICS

		1-S1	3-SC4	3-UC4	4-UC4	4-UC6L	N-UC4
T/W_1		1.6	1.6	1.6	1.5	1.5	1.55
W_{o1}	lbs	902, 850	2, 822, 750	2, 766, 600	6, 205, 403	6, 821, 730	9, 155, 500
T_{total}	lbs	1, 442, 750	4, 516, 400	4, 426, 500	9, 308, 140	10, 232, 600	14, 212, 620
T_{solid}	lbs	1, 432, 390	4, 484, 110	4, 394, 900	9, 241, 270	10, 159, 440	14, 170, 130
W_p total	lbs	594, 330*	1, 688, 000	1, 654, 430	4, 666, 480	5, 211, 800	5, 923, 450
W_p Freon	lbs	21, 440	61, 010	59, 800	168, 670	188, 380	104, 250
W_p solid	lbs	571, 890	1, 626, 990	1, 594, 630	4, 497, 810	5, 023, 420	5, 819, 200
t_{b1}	sec	95.82	87.08	87.08	116.81	118.67	98.56
I_{sp} stage	sec (S. L.)	233	233	233	233	233	236.5
I_{sp} solid	sec (S. L.)	240	240	240	240	240	240
P_c	psia	800	800	800	800	800	800
ϵ_1		8	8	8	8	8	8
λ'_1		.8739	.8598	.8675	.8863	.8874	.8860
W_{s1}	lbs	680, 070	1, 963, 240	1, 907, 110	5, 265, 120	5, 873, 110	6, 686, 730
W_{i1}	lbs	85, 740	275, 250	252, 690	598, 640	661, 310	777, 280

*Includes 1, 000 pounds of hydrogen-peroxide for roll control

Table 4 (Cont.)

VEHICLE CHARACTERISTICS (Continued)

		1-S1	3-SC4 & 3-UC4	4-UC4	4-UC6L	N-UC4
W_{o2}	lbs	222,780	859,500	940,310	948,630	2,468,780
W_{to2}	lbs	221,780	855,590	936,240	944,560	2,459,380
T_2	lbs	200,000	800,000	800,000	800,000	3,000,000
T/W_2		.901	.935	.854	.847	1.22
W_{p2}	lbs	176,800	700,000	700,000	700,000	1,950,000
W_{pres}	lbs	2,980	9,930	15,080	15,610	32,510
$W_{p\ used}$	lbs	173,820	690,070	684,920	684,390	1,917,490
I_{sp2}	sec (vac)	428	428	428	428	428
ϵ_2		27.5	27.5	27.5	27.5	27.5
λ'_2		.9217	.9264	.9256	.9155	.9244
W_{s2}	lbs	192,780	759,500	760,310	768,630	2,118,780
W_{i2}	lbs	14,980	55,590	56,240	64,560	159,380

W_o = Stage Total Weight

T = Thrust

W_p = Propellant Weight

t_b = Burntime

I_{sp} = Specific Impulse

P_c = Chamber Pressure

ϵ = Nozzle Area Ratio

λ' = W_p/W_s

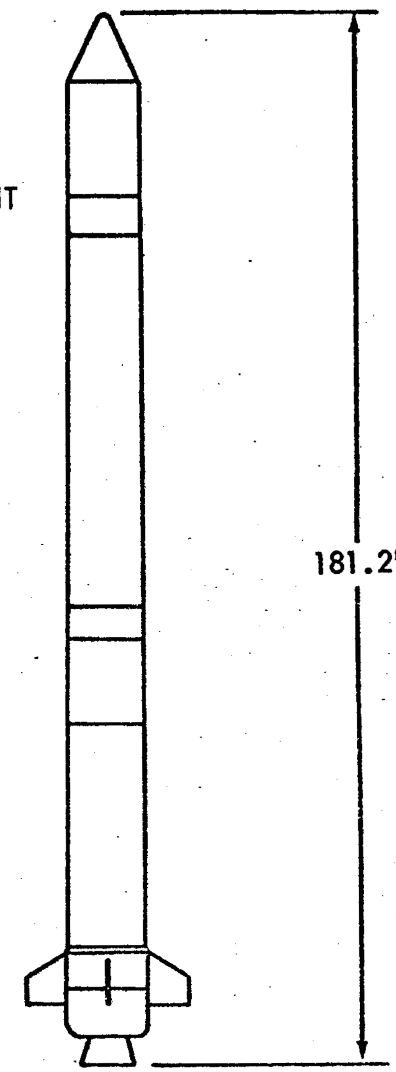
W_s = Step Total Weight

W_i = Step Inert Weight

$W_{to\,2}$ = Second Stage Start-Burn Weight (stage total weight less boil-off and chill-down)

LAUNCH WEIGHT
902,850 LBS.
SECOND-STAGE WEIGHT
191,780 LBS.
SEOND-STAGE PROPELLANT WEIGHT
173,820 LBS.
T_2 = 200,000 LBS.
t_{b_2} = 372 SEC.
λ'_2 = .906

FIRST-STAGE WEIGHT
680,070 LBS.
FIRST-STAGE PROPELLANT WEIGHT
571,890
T_1 = 1,442,750 LBS.
t_{b_1} = 95.8 SEC.
λ'_1 = .874



SCALE: 1 INCH = 400 IN.

Fig. 5 C-1 TYPE
(1-S1 (SEGMENTED)

[redacted]

LAUNCH WEIGHT
2,822,750 LBS.

SECOND-STAGE WEIGHT
755,590 LBS.
SECOND-STAGE PROPELLANT WEIGHT
690,070 LBS.
T_2 = 800,000 LBS.
t_{b_2} = 369 SEC.
λ'_2 = .913

FIRST-STAGE WEIGHT
1,963,240 LBS.
FIRST-STAGE PROPELLANT WEIGHT
1,626,990 LBS.
T_1 = 4,516,400 LBS.
t_{b_1} = 87.1 SEC.
λ'_1 = .860

SCALE: 1 INCH = 400 INCHES

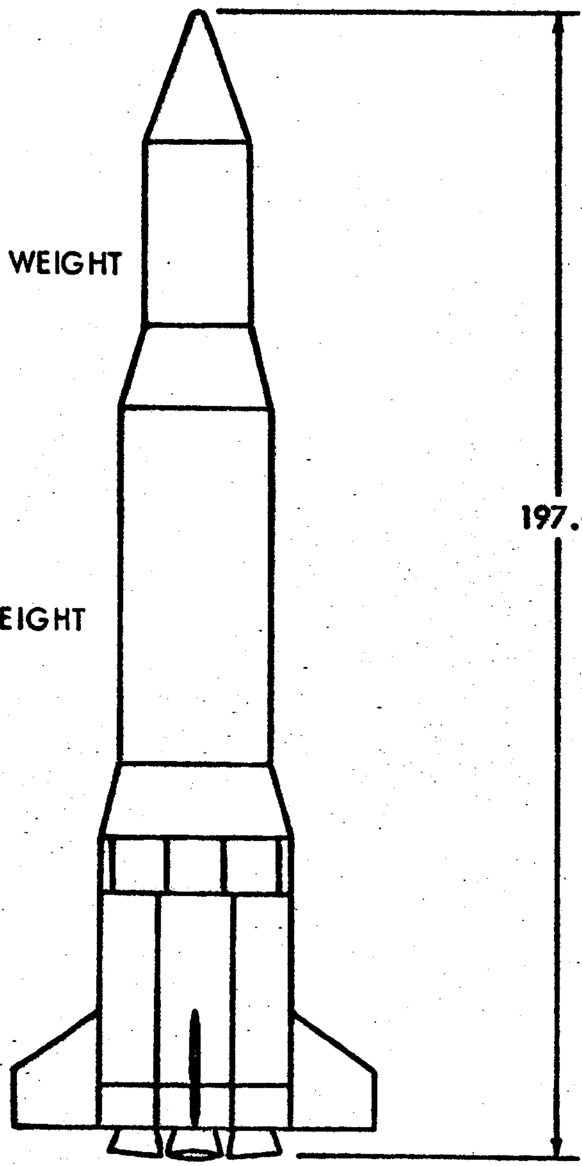


Fig. 6 C-3 TYPE
3-SC4 (SEGMENTED)

[redacted]

LAUNCH WEIGHT
2,766,600 LBS.
SECOND-STAGE WEIGHT
755,590 LBS.
SECOND-STAGE PROPELLANT
690,070 LBS.
T_2 = 800,000 LBS
t_{b_2} = 369 SEC
λ'_2 = .913

FIRST-STAGE WEIGHT
1,907,110 LBS.
FIRST-STAGE PROPELLANT WEIGHT
1,594,630 LBS.
T_1 = 4,426,500 LBS.
t_{b_1} = 87.1 SEC.
λ'_1 = .868

SCALE: 1 INCH = 400 INCHES

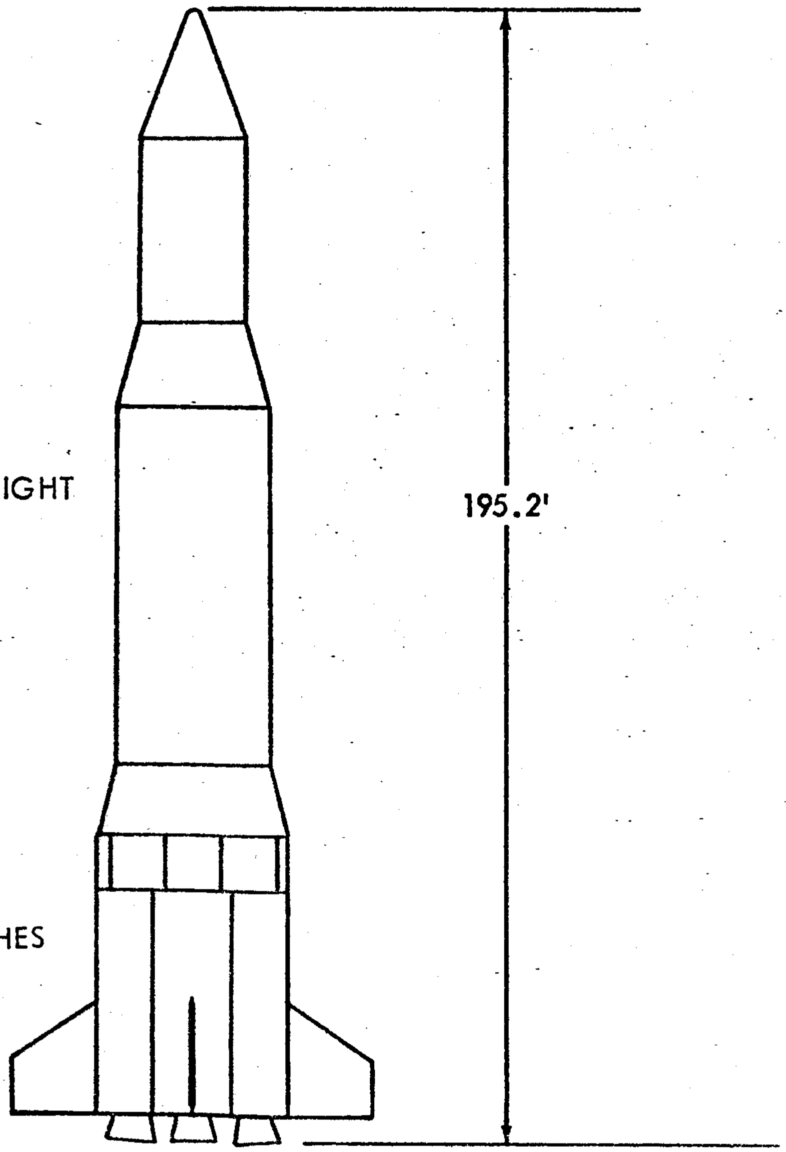


Fig. 7 C-3 TYPE
3-UC4 (UNITIZED)

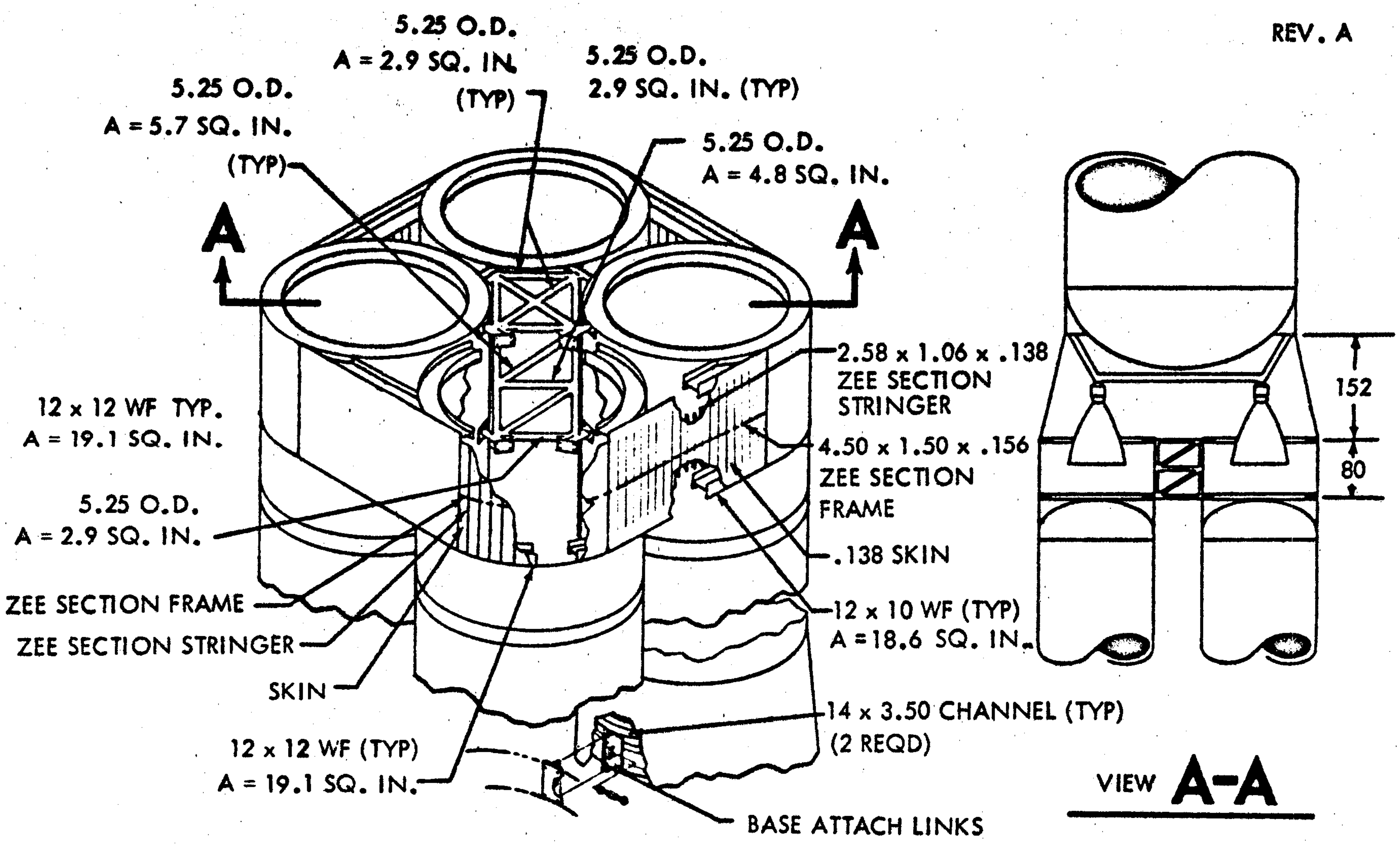


Fig. 8 BOOSTER MOTOR CLUSTERING CONCEPT

located between the clustered motors, pressurized by a hydrazine gas generator. A high thrust-vector-control system reliability is provided through subsystem integration.

180,000-POUND-PAYLOAD VEHICLES 4-UC4 AND 4-UC6L (FIGURES 9 AND 10)

Two concepts of a C-4 type vehicle were studied: the 4-UC4 is a growth of the 3-UC4 vehicle; the 4-UC6L is a laterally staged vehicle with six unitized 160-inch diameter solid motors clustered around the liquid tankage. The 4-UC4 is a tandem vehicle utilizing the same second stage as the 3-UC4 and longer unitized 160-inch diameter solid-propellant motors. Secondary fluid injectant is Freon pressurized in a single tank by a hydrazine gas generator. The 4-UC6L structural concept produced a vehicle weight greater than the 4-UC4. However, this type of lateral staging could prove advantageous on a two-stage solid vehicle where the first stage might be more efficiently clustered about a compact second stage.

350,000-POUND-PAYLOAD VEHICLE N-UC4 (FIGURE 11)

The N-UC4 (a Nova type vehicle) has four 196-inch diameter unitized solid-propellant motors clustered under a liquid-stage powered by three Y-1 engines. The increased motor diameter permits keeping the number of solid stage motors at four; thus, providing high reliability with low cost per pound of payload in orbit. The secondary fluid injectant is nitrogen tetroxide pressurized by stored helium gas. This vehicle does not require fins because of its high moment of inertia. The side impulse required for thrust vector control of this vehicle is very low—one percent of the first stage impulse.

LAUNCH WEIGHT
6,205,430 LBS.

SECOND-STAGE WEIGHT
756,240 LBS.
SECOND-STAGE PROPELLANT WEIGHT
684,920 LBS.
T_2 = 800,000 LBS.
t_{b_2} = 366 SEC.
λ'_2 = .906

FIRST-STAGE WEIGHT
5,265,120 LBS.
FIRST-STAGE PROPELLANT WEIGHT
4,497,810 LBS.
T_1 = 9,308,140 LBS.
t_{b_1} = 116.9 SEC.
λ'_1 = .886

SCALE: 1 INCH = 400 INCHES

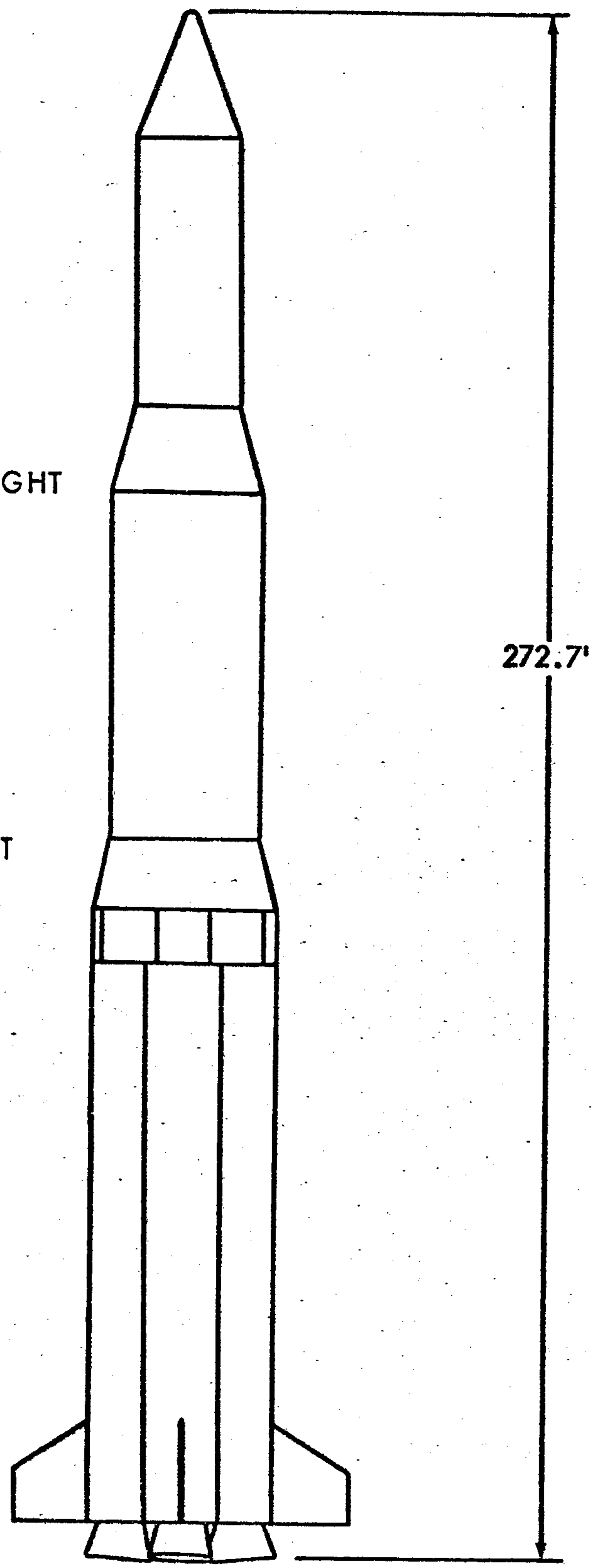
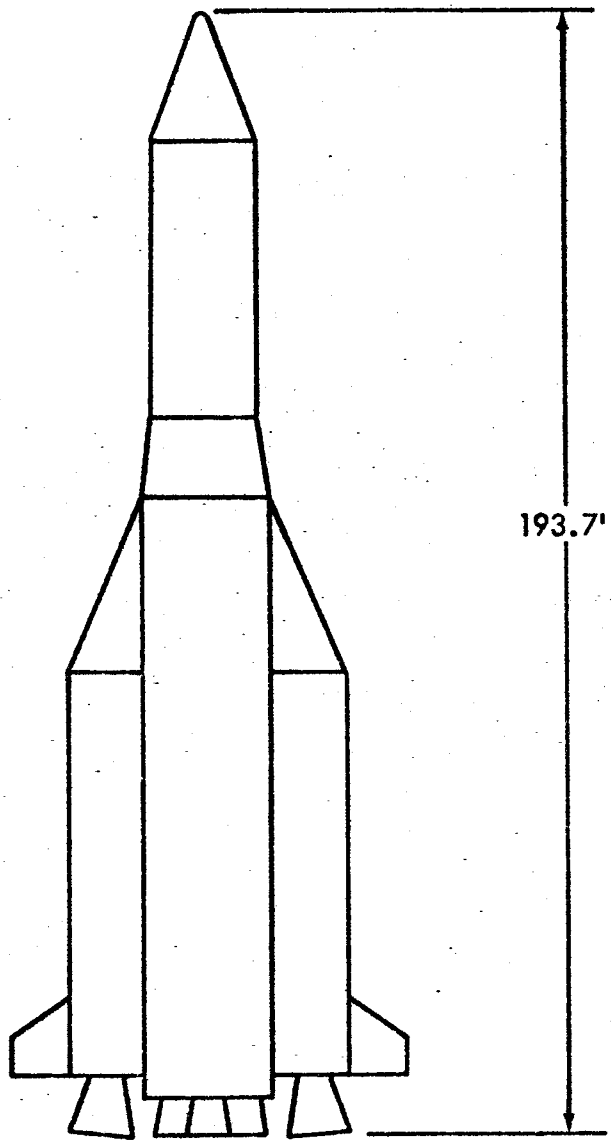


Fig. 9 C-4 TYPE
4UC4 (UNITIZED)

LAUNCH WEIGHT
6,821,730 LBS
SECOND-STAGE WEIGHT
764,560 LBS
SECOND-STAGE PROPELLANT WEIGHT
684,390 LBS
T_2 = 800,000 LBS
t_{b_2} = 366 SEC.
λ'_2 = .895

FIRST-STAGE WEIGHT
5,873,110 LBS
FIRST-STAGE PROPELLANT WEIGHT
5,023,420 LBS
T_1 = 10,232,600 LBS
t_{b_1} = 118.7 SEC.
λ'_1 = .887



SCALE:
1 IN. = 400 IN.

Fig. 10 C-4 TYPE
4-UC6L (UNITIZED)

LAUNCH WEIGHT
9,155,500 LBS.
SECOND-STAGE WEIGHT
2,109,380 LBS.
SECOND-STAGE PROPELLANT WEIGHT
1,917,490 LBS.
T_2 = 3,000,000 LBS.

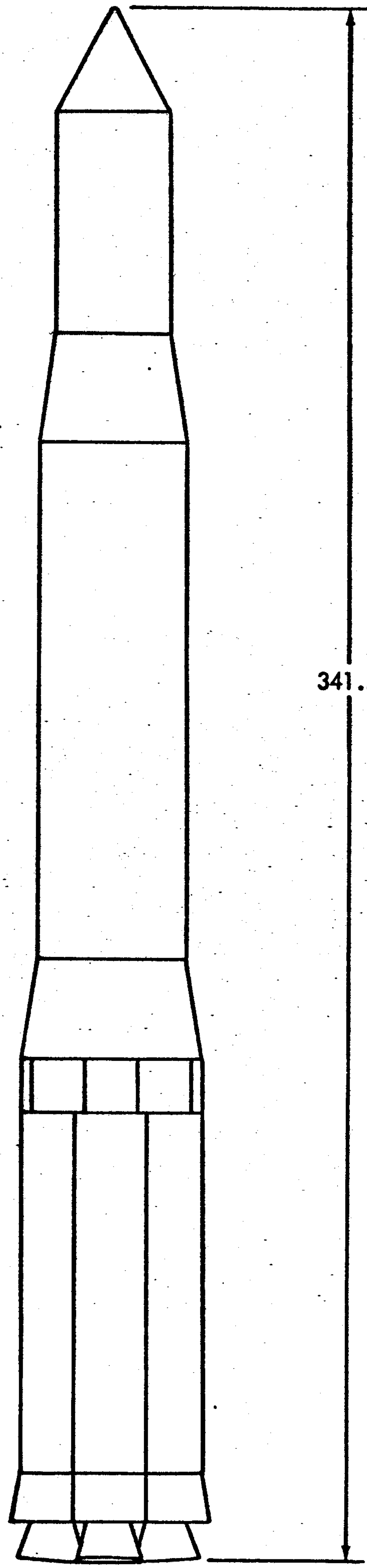
t_{b_2} = 273 SEC.

λ_2' = .909

FIRST-STAGE WEIGHT
6,686,730 LBS.
FIRST-STAGE PROPELLANT WEIGHT
5,819,200 LBS.
T_1 = 14,212,620 LBS.

t_{b_1} = 98,6 SEC.

λ_1' = .886



SCALE: 1 INCH = 400 INCHES

Fig. 11 NOVA TYPE
N-UC4 (UNITIZED)

VI. SYSTEM TEST

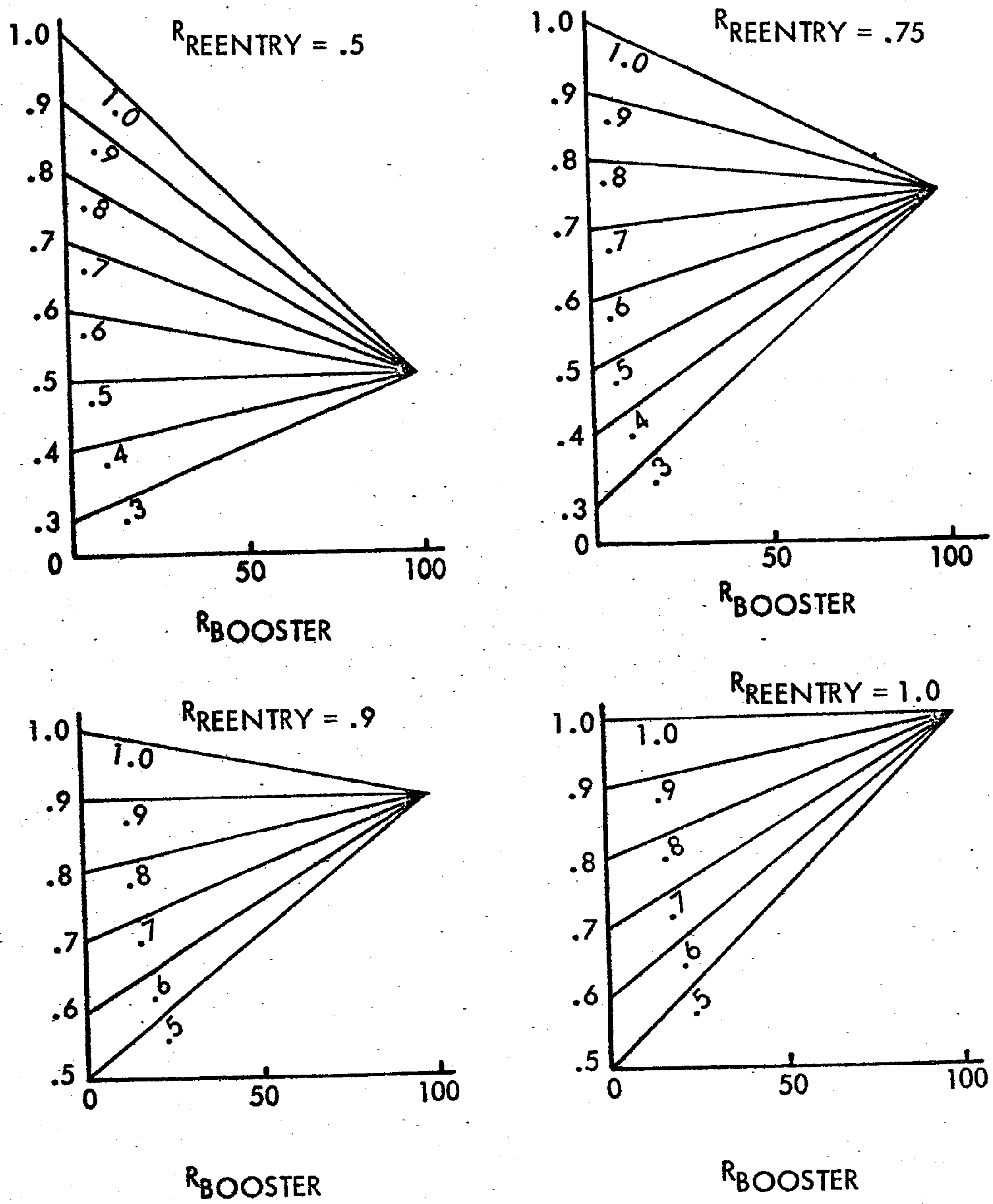
Man-rating of space systems requires a very high degree of safety (payload survivability). An astronaut's career probability of survival must be evaluated rather than single mission survival. If experience gained by space crews is to be profitably utilized, multiple missions must be flown. The number of missions an astronaut can fly is rapidly reduced as single mission safety decreases.

An "all-up" test concept should be used to provide the maximum testing of both escape and re-entry systems. A space mission includes boost, space task, and re-entry. An escape system provides safety in the event of a failure during boost. After completion of the boost phase, the space task must be accomplished, followed by re-entry. Safety can be expressed as the probability of survival during a mission:

Safety = Probability of Successful Mission + Probability of Successful Escape.

= (Reliability of Booster) (Probability of Re-entry) + (1 - Reliability of Booster) (Probability of Escape) (Probability of Safe Recovery)

High levels of safety cannot be achieved without high probability of re-entry and escape; if these probabilities are high, the booster reliability has a lesser effect on safety (see Figure 12). Six successful flight tests are required to produce acceptable confidence in the booster, re-entry, and escape systems. With estimated reliabilities on the order of 0.667 or better—as occurred for all but the largest (Nova type) vehicle studied in detail—nine vehicles will be required for the test program. With an estimated reliability of 0.592 for the Nova vehicle, ten test vehicles should be scheduled.



SUCCESSES ESCAPES

$$P_S = R_B R_R + (1 - R_B) R_E$$

$$= R_B (R_R - R_E) + R_E$$

Fig. 12 CREW SURVIVABLE PROBABILITY

VII. PROGRAM PHASING

A comparative analysis of the 1-S1, 3-SC4, 3-UC4, 4-UC4, and N-UC4 was made in order to determine the variance of first launch and first manned launch. The phasing of these configurations was developed by: 1) identifying the controlling elements of each task; and 2) assessing the time, effort, and complexity interrelationships of these elements for optimum sequence of activities.

Configuration phasing was developed with the following assumption. In all cases the LO_2/LH_2 upper stage was assumed available when required at the vehicle assembly point. It was assumed that prior to R&D contract go-ahead, a preliminary vehicle definition will be established by a special preliminary design contractor—an in-house effort by the using agency—or the initial effort of a system manager or prime contractor. This definition will allow: 1) selection of the motor manufacturer at go-ahead and a motor design complete at 12 months; 2) the establishment of GSE operating plans consisting of general requirements and preliminary design specifications; 3) the early site selection and acquisition of new facilities, when required.

Vehicle phasing summaries are shown in Figure 13. Although the development time for segmented motors is less than for unitized motors, the electric and electronic ground-support equipment are the critical phasing items. The PFRT testing of the unitized motor is also a critical item. In the case of the two vehicles with segmented motors (1-S1 and 3-SC4), the electric and electronic ground-support equipment as well as total vehicle hardware availability are pacing items. Solid motors will be available before they are required. For the remaining three vehicles with unitized motor designs, motor availability is the pacing item.

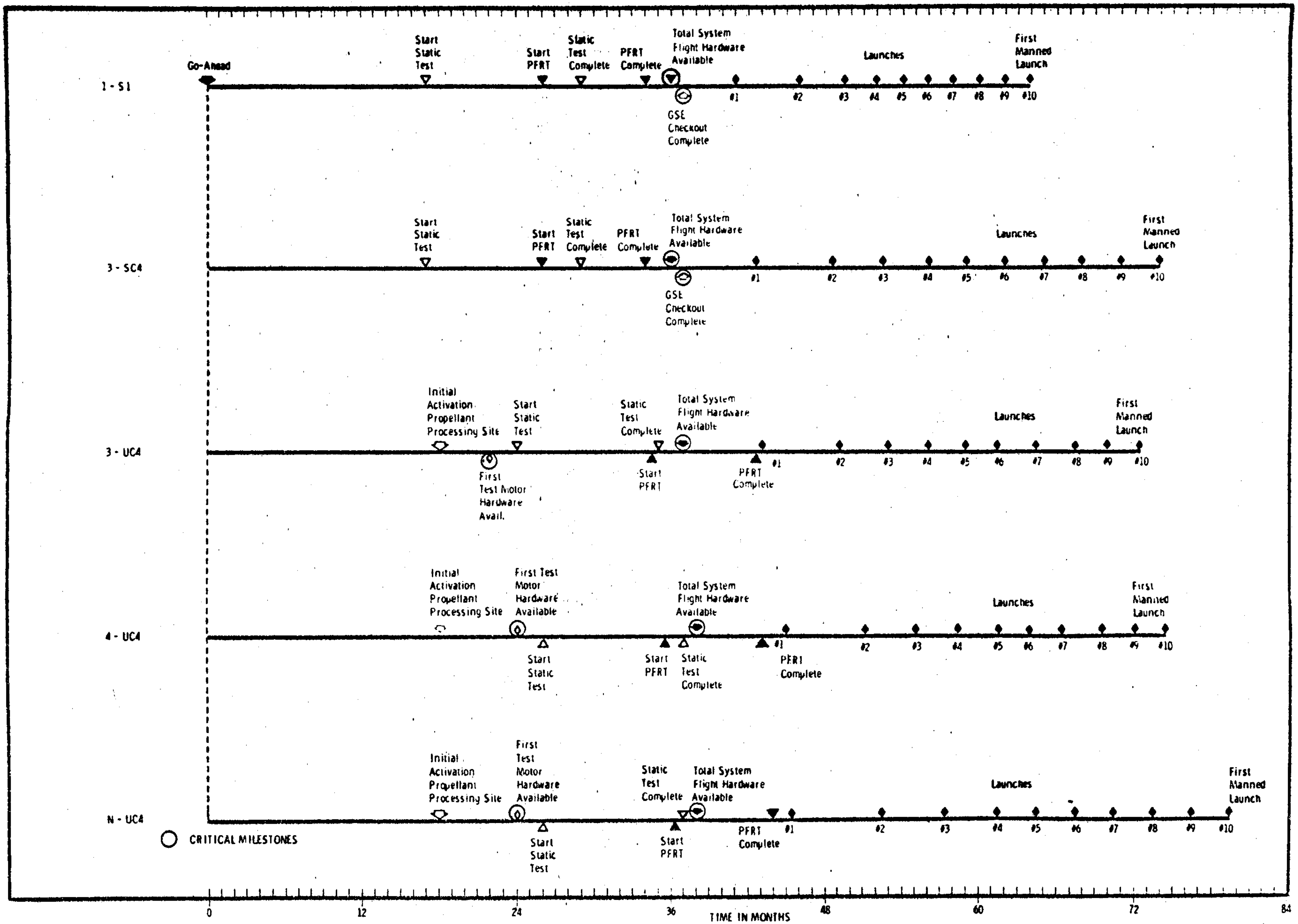


Fig. 13 PHASING SUMMARY

VIII. SYSTEM COST

System costs expressed in terms of dollars per pound of payload delivered to a 307-nautical mile orbit, with assumed 100 percent vehicle reliability, are shown at various operational launch levels in Figure 14. Figure 15 shows the equivalent costs when predicted vehicle reliabilities are included. System costs are also expressed in terms of payload weight, as shown in Figure 16. From this data it is evident that large vehicles and payloads result in the most economical payload delivery systems.

The cost distribution shown in Figure 17 for the C-3 type vehicle is typical. Other indirect costs include GSE, launch base facility, range and general overhead costs. Direct operating costs include propellant, transportation, launch costs, maintenance and spares. As is indicated by Figure 17, depending on the number of launches, 60 to 68 percent of total program costs are for the vehicle and 22 to 30 percent for direct operating costs.

A significant cost factor in the research and development program is the test hardware. Minuteman experience shows that over 70 percent of the solid motor development is for hardware. On the C-3 type vehicle an estimated 236.8 million dollars would be used for hardware costs or 67 percent of the 356.3 million dollar estimated for R&D costs.

A fiscal expenditure plan for the 100,000-pound-payload unitized solid vehicle (C-3 type) is shown in Figure 18 for three different launch rates. The low vehicle launch rate reflects an operational continuation of funding and effort at a level comparable to the R&D program. For the two higher launch rates, because of limited vehicle production and launch capabilities early in the program, annual expenditure rate reaches a peak late in the launch program. This peak could be leveled out by adjusting the launch rate build-up as a function of calendar time.

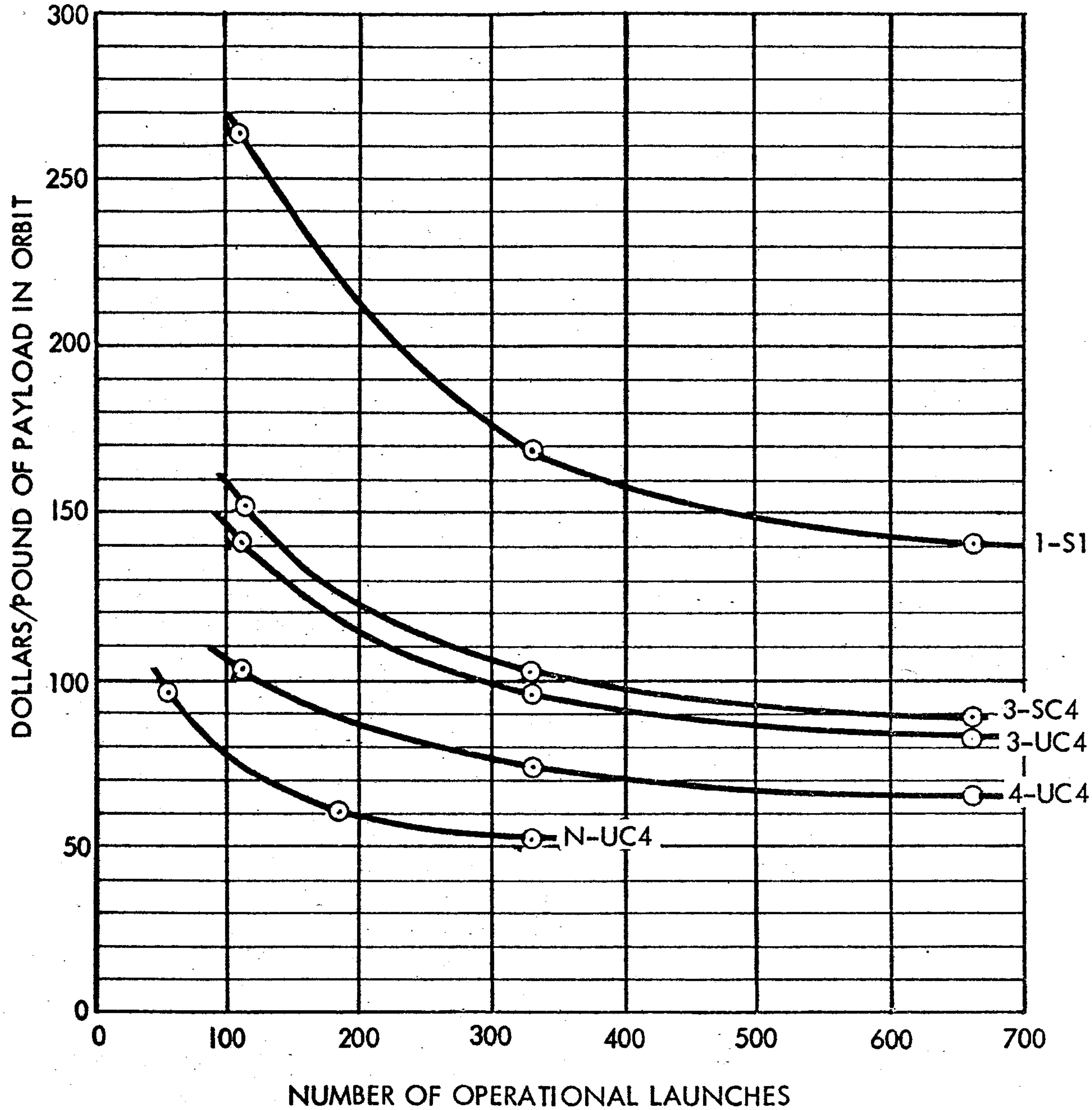


Fig. 14 PAYLOAD IN ORBIT COSTS VS. LAUNCH RATE
100% RELIABILITY

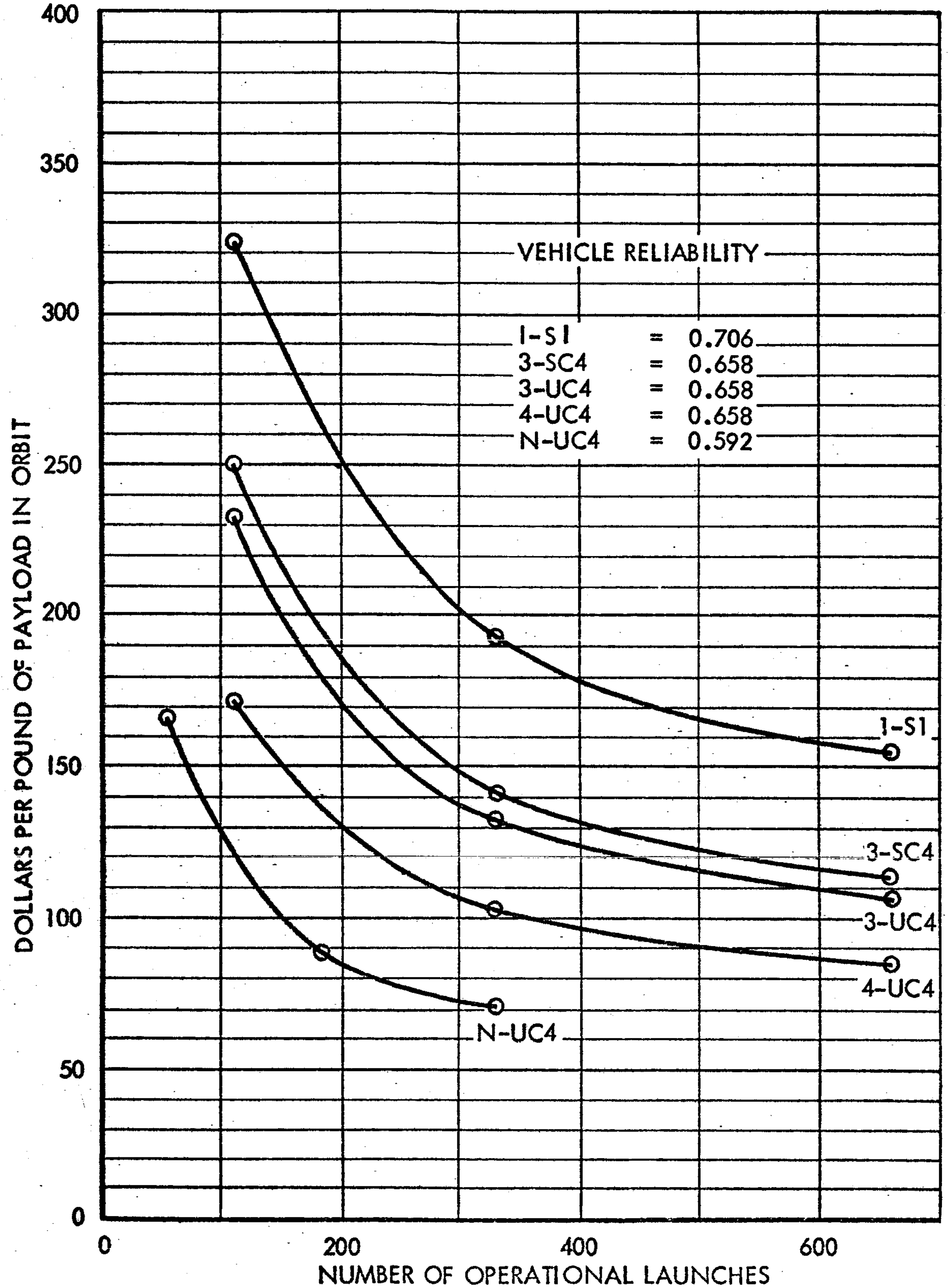


Fig. 15 PAYLOAD IN ORBIT COSTS VS. LAUNCH RATE

PREDICTED RELIABILITY

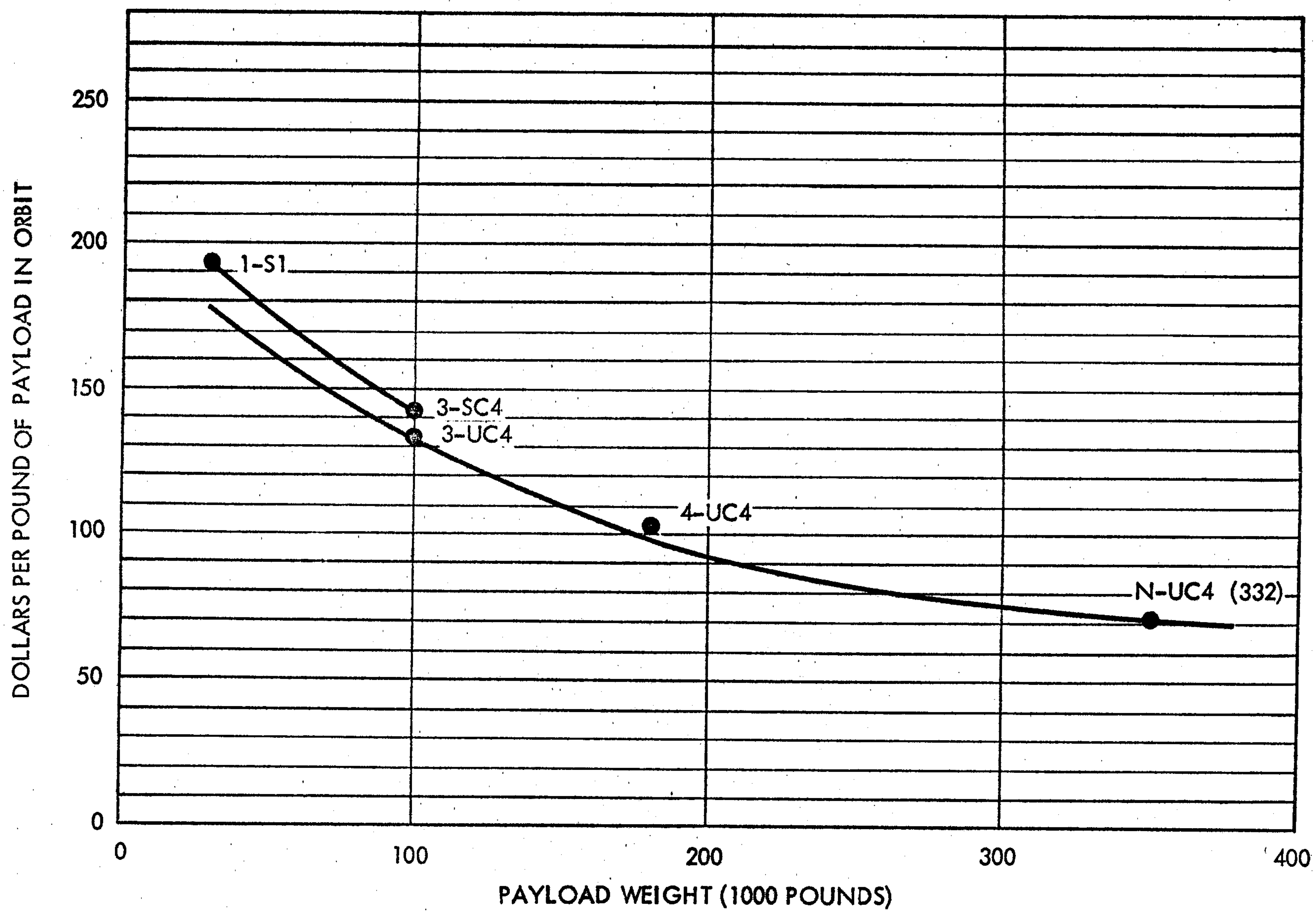


Fig. 16 DOLLARS PER POUND OF PAYLOAD AS A FUNCTION OF PAYLOAD

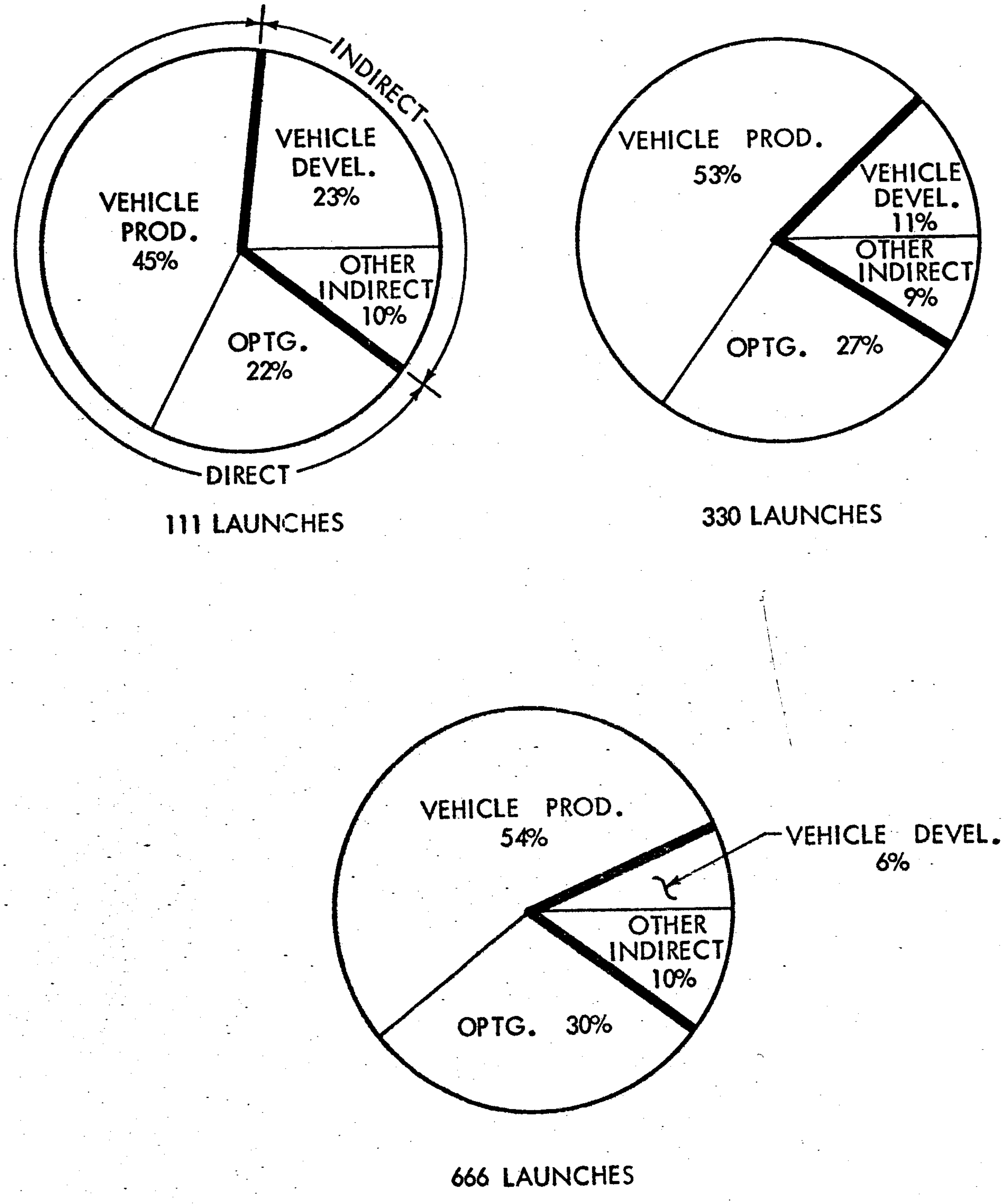


Fig. 17 COST PROPORTIONALITY AS A FUNCTION OF LAUNCH SCHEDULE

3-UC4

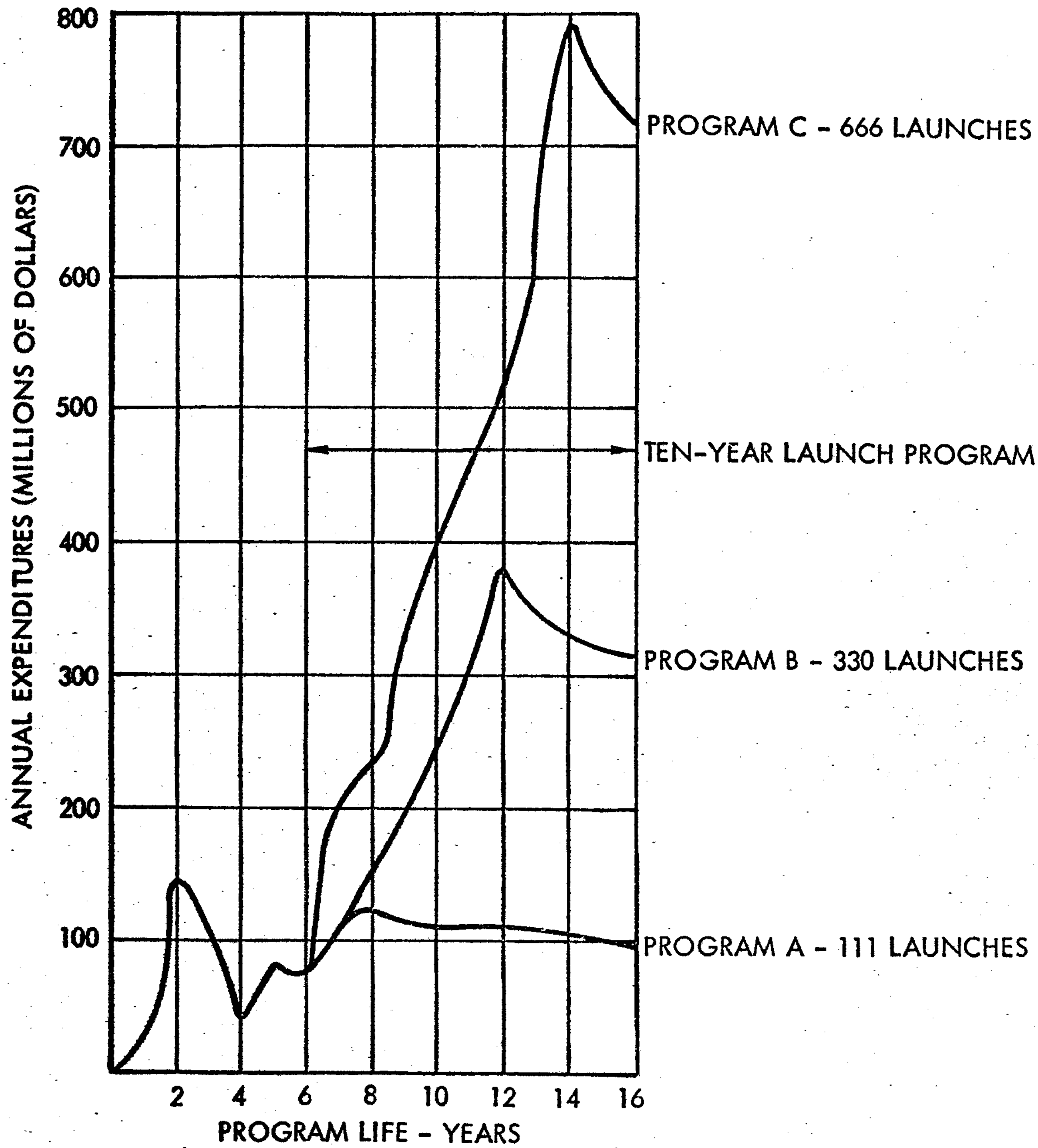


Fig. 18 PROBABLE EXPENDITURES FOR 3-UC4 BY YEAR

Direct and indirect funding of the C-3 type vehicle for 330 launches is shown in Figure 19. Significant indirect funding is required during the operational program of high launch rates to provide additional launch facilities.

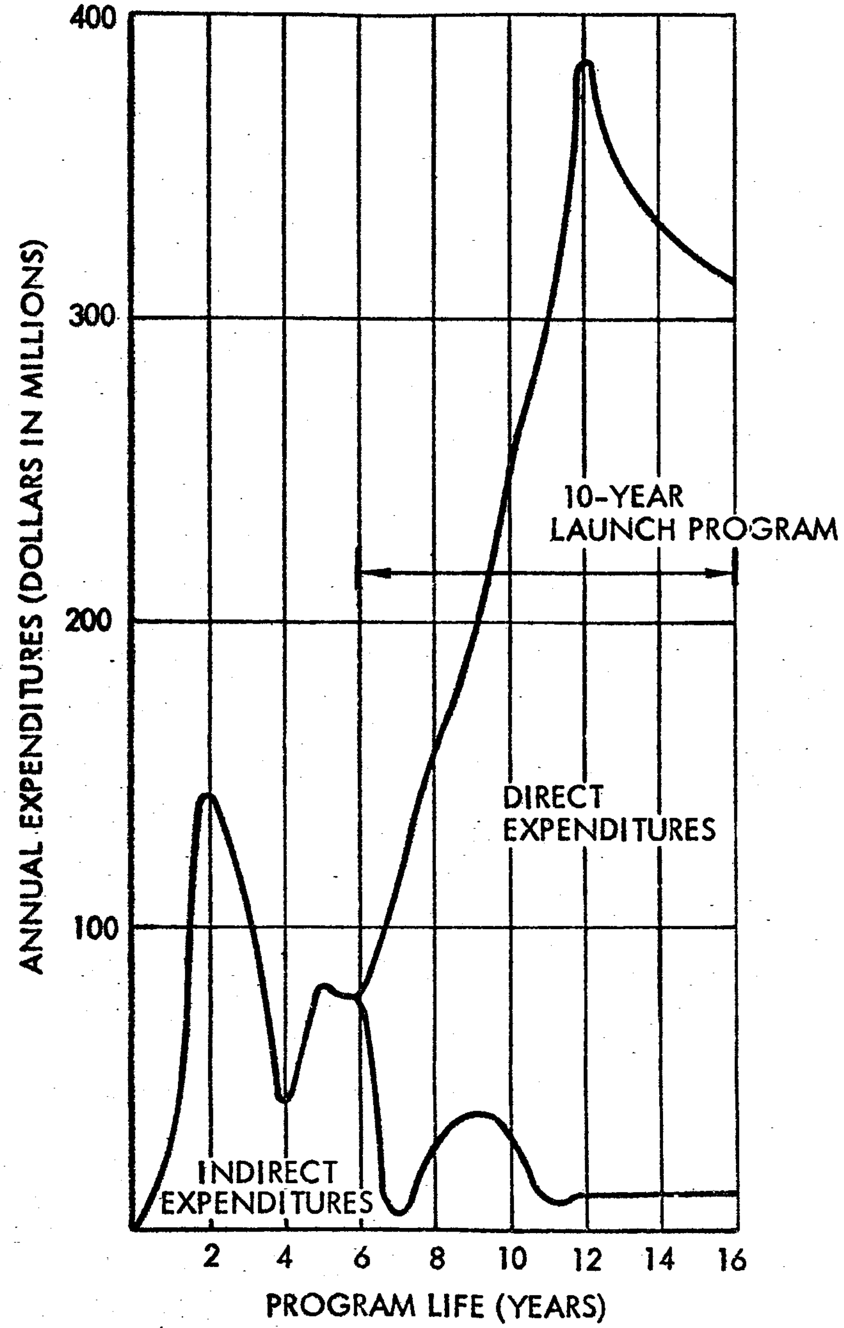


Fig. 19 PROBABLE DIRECT & INDIRECT EXPENDITURES
VEHICLE 3-UC4 -- 330 LAUNCHES

IX APPENDIX

A. GROUND RULES

1) Ground Rules Established by Contract Prior to the Study:

a) Mission of 307-nautical mile (96-minute) circular orbit

b) Vehicle launching at AMR with an azimuth of 90° from the north and launched in an easterly direction

c) Dynamic pressure limits of 1200 psf maximum and 400 psf maximum at staging

d) Vehicle acceleration limit of 8 g

e) Liquid-stage propellant reserves to provide for 3-1/2 percent of total vehicle boost velocity, 1 percent for propellant utilization, and additional propellant for lines, etc., as required

f) Vehicles consist of one or two solid stages and one liquid stage. The liquid stage uses LO_2/LH_2 propellant, tandem integral tankage, and bell-nozzle engines.

g) Vehicle payloads and liquid-stage engine thrust and number of engines studied in Phase II are defined for each vehicle as follows:

Vehicle Payload	30,000	100,000	180,000	350,000
Liquid Engine	J-2	J-2	J-2	Y-1
Number of Engines	1	4	4	3 or 4

h) Vehicle launch rates specified in Tables 1A and 2A

i) Tandem staging is employed on all vehicles except one 180,000-pound payload vehicle with solid motors laterally staged about the liquid stage.

2) The following design criteria were established by Boeing on a "best Engineering judgement basis" to allow the study to proceed on the broadest front possibl

a) Structural Materials

(1) Solid motor cases use 200,000-psi UTS heat-treated steel

(2) Cryogenic tankage uses 59,500-psi UTS weldable aluminum (70°F)

(3) Interstage and miscellaneous structure use 70,000-psi UTS high-strength aluminum

b) Structural Safety Factors

(1) Ultimate safety factor = 1.40

(2) Yield safety factor = 1.10

(3) Weld efficiency = 90 percent

(4) Solid-motor limit chamber pressure factor = 1.23

(5) Thrust vector control tankage safety factor = 2.50

c) First-Stage Motor Type—Phase II

(1) Segmented motors used on 30,000- and one 100,000-pound-payload vehicles

(2) Unitized motors used on one 100,000-pound payload vehicle and the 180,000- and 350,000-pound-payload vehicles.

d) Solid-Motor Design

(1) Burntime less than 120 seconds

(2) Chamber pressure = 800 psia

(3) Nozzle expansion ratio = 8.0

(4) Constant solid-motor chamber pressure (sea level) was assumed for vehicle performance.

(5) Fluid injection thrust-vector-control system.

e) Liquid-Stage Design

(1) No boost pumps

(2) Oxidizer minimum pump NPSH 25 feet, ullage pressure 32 psia, pressurized by GO_2 over LO_2

(3) Fuel minimum pump NPSH 325 feet, ullage pressure 27 psia, pressurized by GH_2 over LH_2

Table 1-A

ASSUMED LAUNCH RATES FOR VEHICLES 1-S1, 3-SC4, 3-UC4, 4-UC4 and 4-UC6L

OPERATIONAL YEAR	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Total
Program A	6	9	12	12	12	12	12	12	12	12	111
Program B	6	9	15	24	36	48	48	48	48	48	330
Program C	9	15	24	36	54	72	96	120	120	120	666

Table 2-A

ASSUMED LAUNCH RATES FOR VEHICLE N-UC4

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Total
Program A	2	4	6	6	6	6	6	6	6	6	54
Program B	4	6	12	18	24	24	24	24	24	24	184
Program C	6	10	16	24	36	48	48	48	48	48	332